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ENGINEERING DESIGN, CONSTRUCTION, OPERATION AND ANALYSIS OF THE 2007 TEXAS A&M UNIVERSITY SOLAR DECATHLON HOUSE

A Final Examination Report

By

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Submitted in partial fulfillment of the requirements for the degree of

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ENGINEERING DESIGN, CONSTRUCTION, OPERATION AND ANALYSIS OF THE TEXAS A&M UNIVERSITY SOLAR HOUSE PRESENTED AT THE SOLAR DECATHLON 2007

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ABSTRACT

Engineering Design, Construction, Operation, and Analysis
of the 2007 Texas A&M Solar Decathlon House (May 2008)
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Co-Chair of Advisory Committee: Dr. Jeff S. Haberl
Co-Chair of Advisory Committee: Dr. W. Dan Turner

This report presents the design, construction, and operation of a 100% solar-powered house from an engineering perspective. This includes energy simulation results, selection of systems, design of systems, assembly of systems, integration between architectural and engineering design, transportation of the house to Washington D.C., and a review of the actual performance of the house during the 2007 Solar Decathlon. The house was designed and constructed in Bryan-College Station, Texas, from January 2006 to September 2007. It was constructed at the Texas A&M University (TAMU) facilities and it was then transported to the National Mall in Washington, D.C. for the U.S. Department of Energy's Solar Decathlon which took place from October 3 to October 23, 2007. A full-description of this project is presented along with the TAMU team's strategy for the competition contests. Finally, an analysis of the final outcome is offered with recommendations for future events.

ACKNOWLEDGEMENTS

I wish to thank Dr. Jeff S. Haberl for his guidance and supervision during the course of this project. I would also like to thank Dr. W. Dan Turner for his patience and support.

Thanks also are owed to every student, staff member, and to the faculty that helped in making this project possible. I am grateful to my colleagues at the Energy Systems Laboratory, including Mini Malhotra (DOE-2 Analysis), Soolyeon Cho (F-Chart Analysis), and Piljae Im (PV F-Chart Analysis) for their help in the simulations of the Solar House and to Dr. Liliana Beltran, Alaina Jones, and Simge Andolsun for their input in the daylighting simulation (RADIANCE, DAYSIM, ECOTECT).

Finally, I would like to thank my wife Lynette for standing strong right next to me during the long hours devoted to this project and my graduate studies.

Table of Contents

Table of Figures

List of Tables

Chapter 1: Background

Section 1.1. The Solar Decathlon

The Solar Decathlon (SD) is an interdisciplinary project organized by the U.S. Department of Energy (DOE) with the intention of challenging the student competitors to think in new ways about renewable energy and how it impacts people's lives. It also indirectly encourages the consumers that visited the competition to make more responsible energy choices. With this project, the DOE is also trying to push research and development of energy efficiency and energy production technologies. The SD complements the Solar America Initiative (US Department of Energy, 2006), which seeks to make solar energy cost-competitive with conventional forms of electricity by the year 2015.

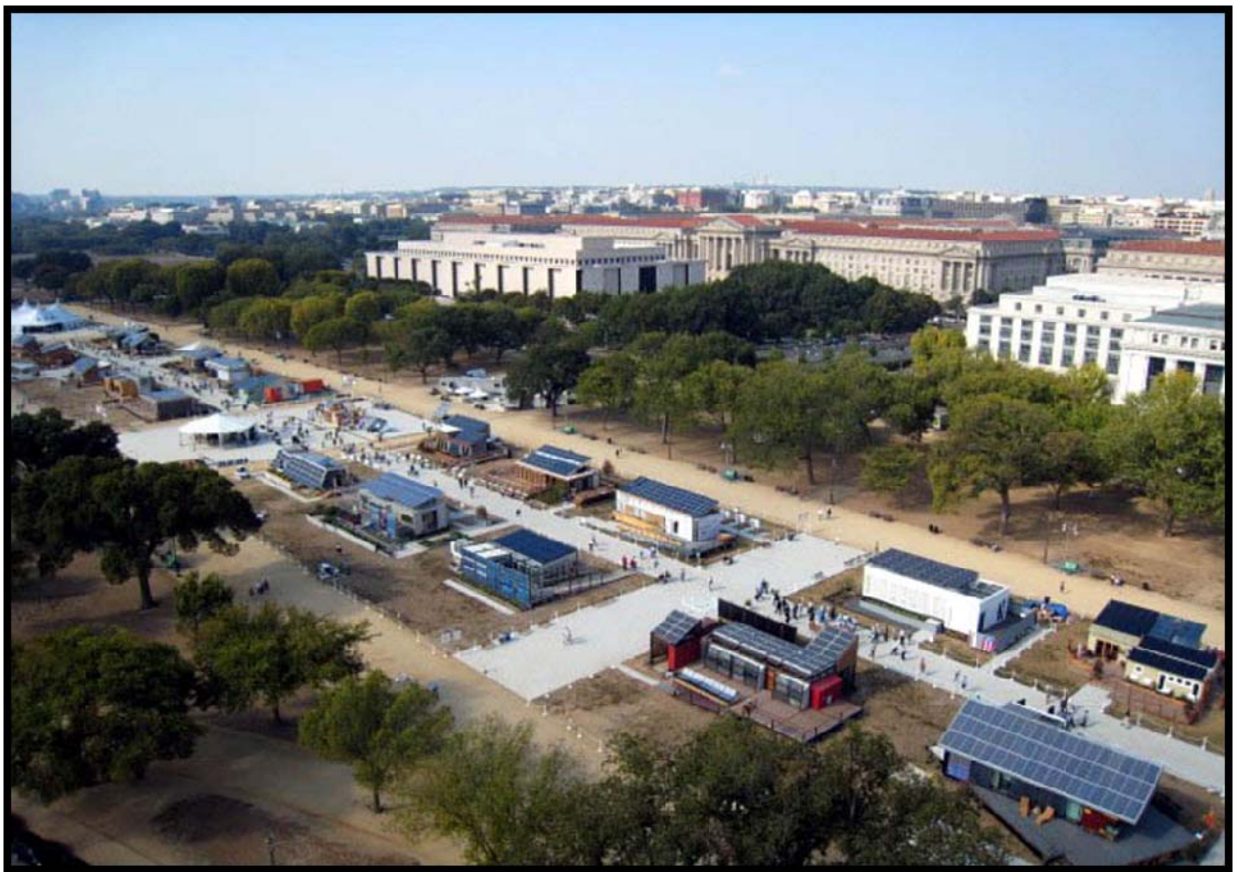


Figure 1: View from the solar village at the National Mall in Washington, DC (photo by Richard King).

In the competition, students are challenged to design, build, and operate a 100% solar powered house following the rules, regulations, and standards including the National Electrical Code (NEC), the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), and the Illuminating Engineering Society of North America (IESNA) among others. After designing, building, and testing their houses, each team transports their house to the National Mall at Washington, DC, forming a solar village. Subsequently, after each house arrives at the National Mall, teams have approximately ten days to reassemble and prepare for a week of contests, then disassemble the house and return home. Figure 1 shows a view of the 2007 solar village.

The decathlon concept comes from the ten contests that compose the competition. These contests are considered objective, subjective, and a combination of objective and subjective. For the objective contests the points are awarded by sensor readings and/or completion of tasks. In contrast, the subjective contests are judged by experts in the field of the contest. The ten contests are:

- Architecture (200 pts)
- Engineering (150 pts)
- Market Viability (150 pts)
- Communications (100 pts)
- Comfort Zone (100 pts)
- Appliances (100 pts)
- Hot Water (100 pts)
- Lighting (100 pts)
- Energy Balance (100 pts)
- Getting Around (100 pts)
- Total Points = 1200 pts

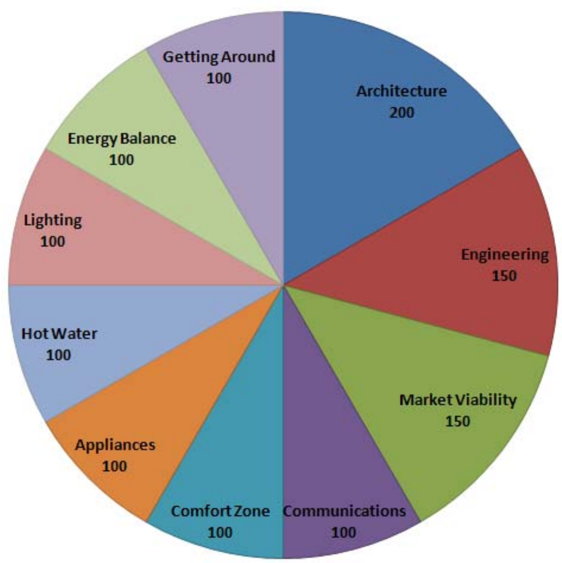


Figure 2: Points distribution for the SD 2007

The rules and regulations of the competition are explained in detail on the Solar Decathlon website (www.solardecathlon.org) (National Renewable Energy Laboratory, 2007).

Section 1.2. Impact

The Solar Decathlon has had a major impact on the participating students, faculty, universities, and private companies that have participated in the three competitions since 2002. Students have the unique opportunity of learning and growing as professionals and individuals. They learn the technical aspects of engineering, architecture, project management, and other areas that are not typically learned on research activities or other student projects. This type of interdisciplinary project allows them to go beyond their areas of expertise and understand the importance of integration and communication within a team, which provide a solid base for their future as professionals. The competition also provides an opportunity for faculty members to cross the classroom lines and create a deeper relationship with students. It also helps professors to expand their network with professionals from the private sector not only for future research projects but also to see and evaluate new research areas. Universities receive a nationwide exposure, having the opportunity to show their commitment to the education and the development of new technology in areas such as energy efficiency, renewable energy resources, and sustainable design. Last but not least, private companies have the opportunity of showcasing their products to millions of people around the globe.

Section 1.3. Texas A&M University Entry

The Texas A&M University (TAMU) house was one of the twenty universities selected to participate in the 2007 Solar Decathlon. All the twenty teams had to submit a proposal in the fall of 2005, which was then reviewed and accepted by a selection committee from the DOE. The original design concept for the TAMU house was created by Prof. Pliny Fisk III and is called the “gro-Home”. The concept is centered on the idea of plug-and-play, which utilized a modular steel frame for the house and its gro-walls that contained the plumbing, electrical, and HVAC systems. Figure 3 presents a rendering of the final design of the house.

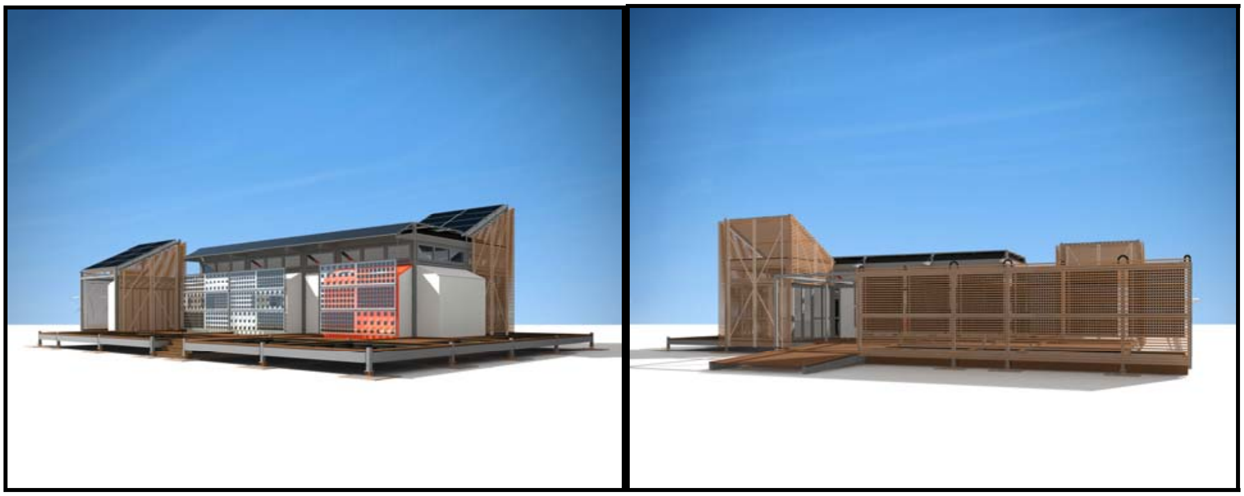


Figure 3: Final renderings of the TAMU house.

Chapter 2: Literature Review

Section 2.1. Previous Solar Decathlons

The first edition of the SD was held in 2002, with 14 universities participating in the premiere solar technology showcase. It returned in 2005 and again in 2007. The next U.S. Solar Decathlon is scheduled for 2009. In addition, a new international Solar Decathlon is scheduled for 2010 in Madrid, Spain. In each of the contests the competition has increased with the houses becoming more sophisticated. The evolution of its rules and regulations and the solar technologies help to create more professional and interesting designs. The growth of the competition has reached worldwide recognition and participants include not only the best universities from the U.S. but also the best universities from Germany, Canada, Spain, and Puerto Rico. Different perspectives regarding the Solar Decathlon experiences had been documented by different teams (Safavi & Strueber, 2004) (Brandhorst, 2003), which show that every house and team's experiences were unique.

After every edition of the Solar Decathlon, a final summary of the event including participants, final results, and specific details is presented by the DOE (Eastment, et al., 2004)

(Moon, et al., 2006)[1]. In addition to these final summaries, an explanation of the simulation and monitoring procedures for the competition's objective contests has been documented (Wassmer & Warner, 2005), revealing the technical challenges of the organizers to accurately monitor several houses at the same time.

There are also several papers that focus on the engineering perspectives of the project. In these papers two main areas are usually presented: simulation models (Choudhary, et al., 2007) and the design of the photovoltaic and mechanical systems (Pasini & Athienitis, 2006). The 2005 edition of the Solar Decathlon was especially challenging due to the lack of sun during the contest week. In 2005, the strategy used by the winning teams had a big role in the final results. In 2005 it was found that the effect of the operation of the photovoltaic systems was crucial (Warner & Wassmer, 2006), effectively converting the solar competition into an impromptu battery management competition.

Section 2.2. Interdisciplinary Project

Finally, there are several papers that analyzed the educational aspects of the competition. These papers emphasize on the importance of the interdisciplinary projects in the development of professionals (Ellis, 2003) (Chuku, et al., 2003).

Section 2.3. Building Performance

Many of the houses that compete in the Solar Decathlon are used by their institutions as tools for future research activities. One research area that benefits directly from this is the design, simulation, and optimization of Zero Energy Homes (Charron & Athienitis, 2006) (Charron, et al., 2005). Another building performance related project was performed on the

[1] At the time of writing this report, the final summary for the Solar Decathlon 2007 is still in preparation.

Pittsburgh Synergy team from the 2005 edition. Since 2005 this house has been used to assess the accuracy and usefulness of building performance simulation tools (Yezioro, et al., 2008).

Chapter 3: Engineering Design

Section 3.1. Restrictions and Challenges

Like every competition, there are rules and restrictions that make the experience challenging. The restrictions for the 2007 Solar Decathlon are mentioned in Table 1. These restrictions are very important in the development of the project. Usually, students are not familiar with such rules, codes, restrictions, etc. Therefore, a period of research and brainstorming is imperative early in the project in order to design and select existing technology that will match the vision, mission, and concept presented on the accepted proposal that meet all rules, codes, and regulations that can change through-out the project.

Another major factor in the intelligent design of a house is to understand the location where the house is been designed. In the contest rules for 2007 the teams were required to design their house for their location, yet show, using simulation, that the house will function in Washington, D.C. in October where the yearly weather conditions may be different for tropical, sub-tropical, and colder climates. An example of the climate variations is presented in Figure 4, Figure 5, and Figure 6. Figure 4 shows the climate zones in the U.S. (Briggs, et al., 2003) as presented in the 2004 IECC Supplement and adopted by organizations such as ASHRAE, Building America, and Energy Star (DOE, 2006). Figure 5 and Figure 6 show that the radiation intensity and average dry-bulb temperatures are very different depending on the different regions within the US. Therefore, depending on climate zone the house was designed for, teams may have difficulties in Washington D.C, in October during the week-long competition.

Table 1: List of restrictions and challenges for the SD teams.

Restrictions and Challenges:	Details:
Solar Decathlon Rules and Regulations	Rules developed by the DOE for safety, contests, and operation of equipment.
National Codes and Common Practices	NEC, Building Code, Fire code, ADA, IESNA, ASHRAE, ASSE, UL, ICC.
Monetary Support	Depends on the team's fund raising strategy. Donations may come in different forms: money, expertise, equipment, time, etc.
Time	Every team has two years to design, construct and transport their house to Washington, D.C.
Design for a Specific Location	Every team should design for their local conditions plus have a viable design for the contest period in Washington, D.C.

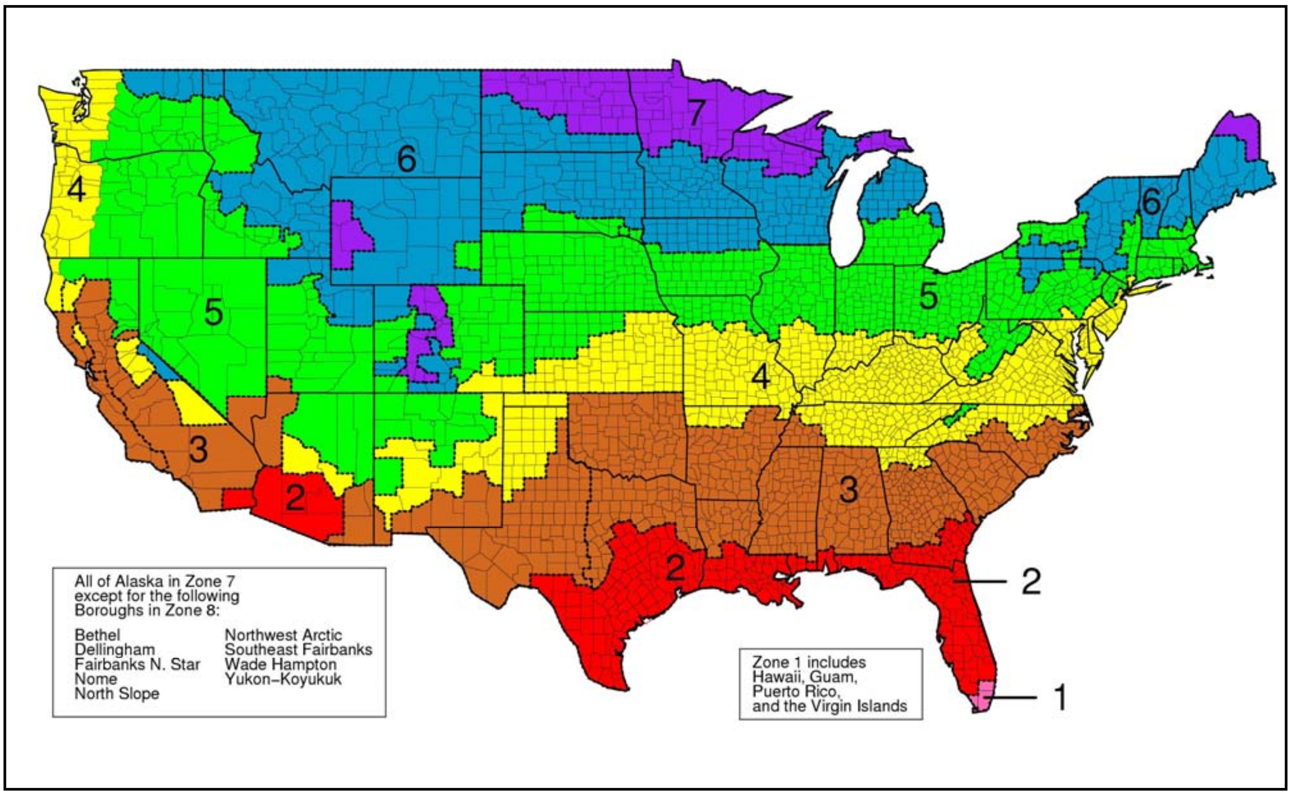


Figure 4: Climate zones for the U.S. (Climate zones (by county) for the 2004 supplement to the IECC, the 2006 IECC, and ASHRAE 90.1-2004).

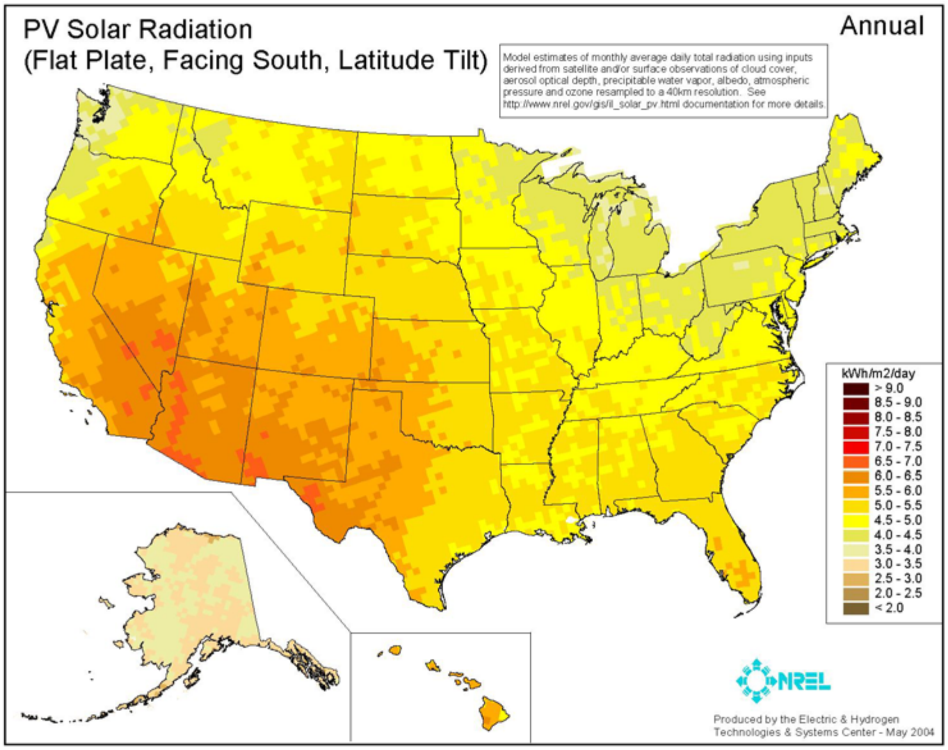


Figure 5: Annual available solar radiation for flat plate collectors (www.nrel.gov/gis/images/us_pv_annual_may2004.jpg).

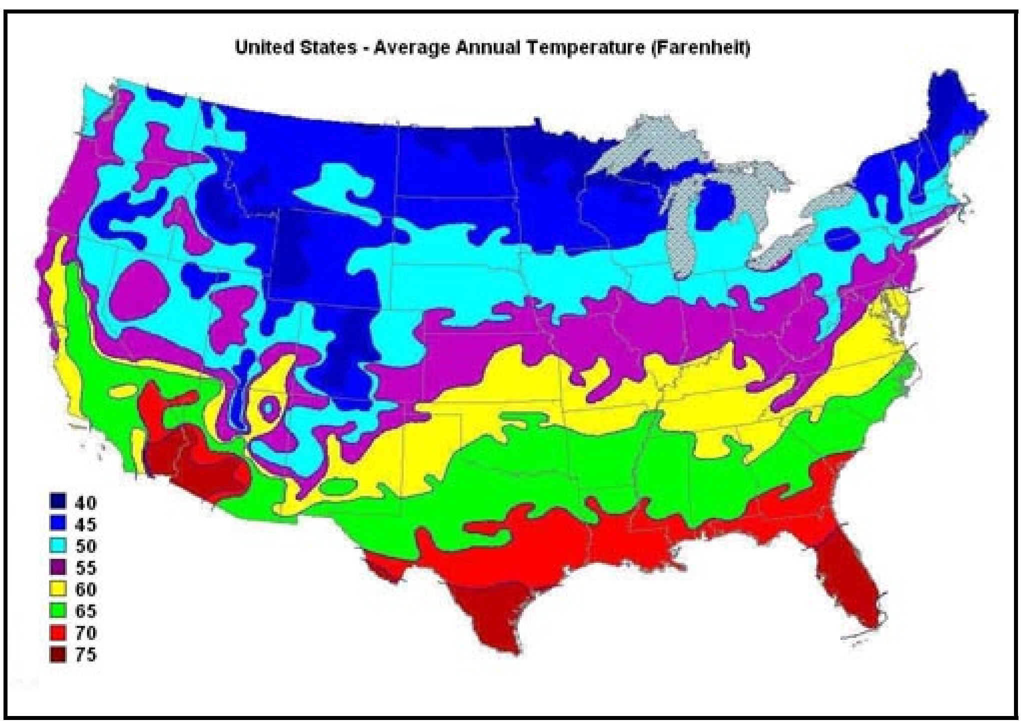


Figure 6: Average Annual Temperature for the U.S. (my.athenet.net/.../pics/gbppr-usa-temp.jpg)

Section 3.2. Familiarization Period

When teams are formed by students it is necessary to find a way to familiarize them with the different types of solar systems and simulation programs. Professors are crucial at this time of the project since they have varying amounts of knowledge on the different topics. There are multiple ways of achieving the familiarization with the systems. The method used at the TAMU house was the research/prototype approach in which students researched books and the internet in order to review and understand the systems. Then, the students built prototypes that forced them to see the physical challenges that come with different systems. Figure 7 and Figure 8 show the solar thermal and photovoltaic system prototypes used for the TAMU house.

Figure 7: Solar thermal system prototype.

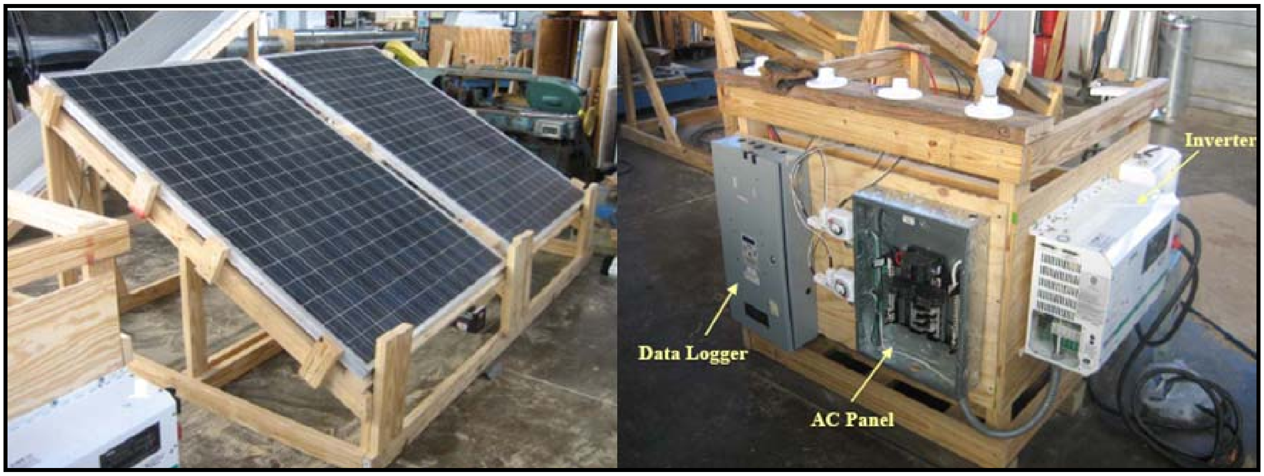


Figure 8: Photovoltaic system prototype.

For familiarization with the simulation programs, the TAMU students had knowledge about several simulation programs from their academic coursework. With the help of the supervising faculty from these courses, it was possible for the students to simulate all aspects the house and the different systems including: the building’s thermal use, solar thermal, photovoltaic, lighting and daylighting.

Section 3.3. Architecture/Engineering Integration

Section 3.3.1. Envelope

The total footprint of the TAMU house was 800 sq. ft. The exterior walls had R-7.5, bio-based, spray-in foam insulation between the metal frames, and 2” thick, R-8 foam core architectural panels as exterior finish. The roof and the raised floor had 8” thick, R-34 structural insulated panels between the metal beams.

The gross window area was 384 sq. ft. that includes: operable 1’-8” clerestory windows on all sides, vision glazing on the south, and glazed walls and sliding glass doors facing north and west, respectively. All the windows were Ar-filled, with quadruple pane glazing and fiberglass frames. The glazing assembly has two clear glass panes, and two heat mirror films.

The glass assembly has a U-value of 0.08 Btu/h-ft2-F (which is equivalent to R-12). The East, West, and North windows had a 0.27 SHGC (solar heat gain coefficient). The south windows had 0.44 SHGC to allow higher solar gain during the winter (i.e. passive solar).

The design of the conditioned space used for the energy analysis simulation was a 460 sq. ft., single-story, one-bedroom house elongated along the east-west axis (Figure 9). DrawBDL (Huang, 2002) renderings of the DOE-2 input file were used to provide feedback regarding the simulation configuration (Figure 10). The lighting, domestic hot water, and appliances loads and usage profiles, obtained from the USDOE's Building America Research Benchmark Definition (Hendron, 2005) were used to determine the internal gains.

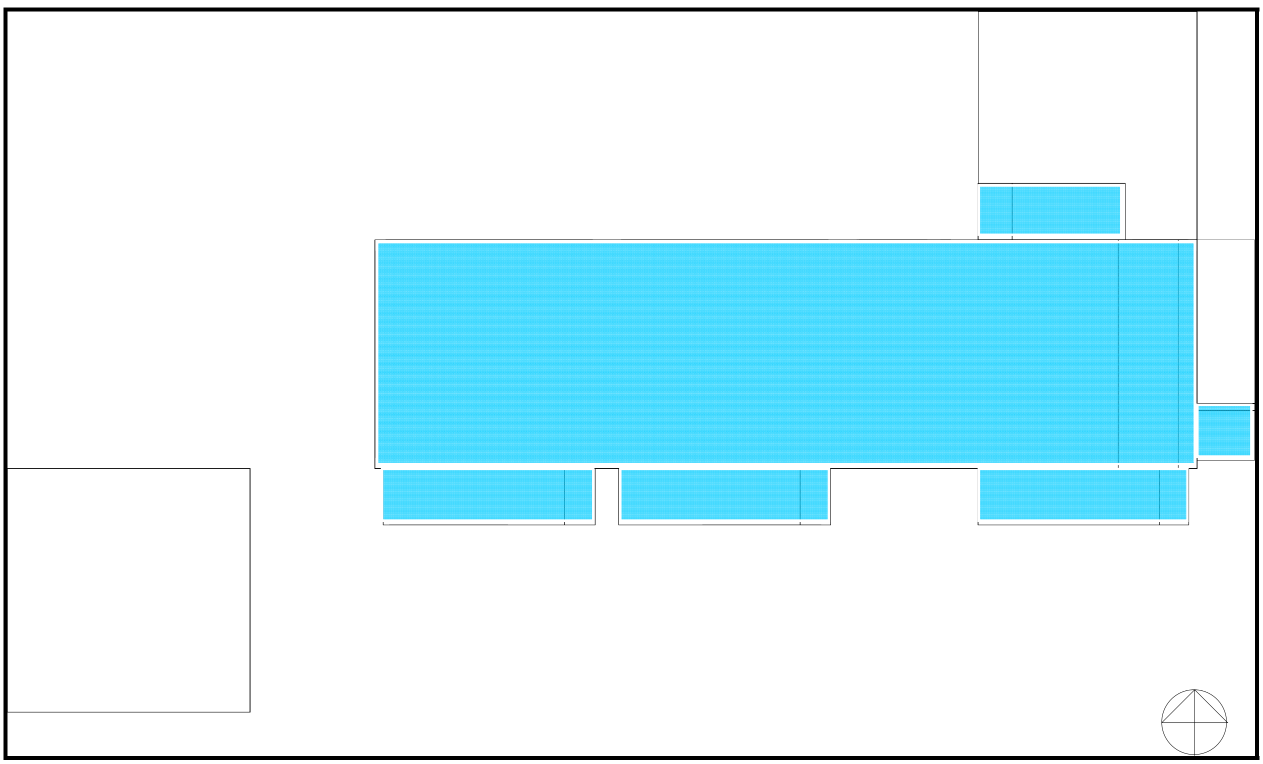


Figure 9: Conditioned area plan. Blue spaces are conditioned space.

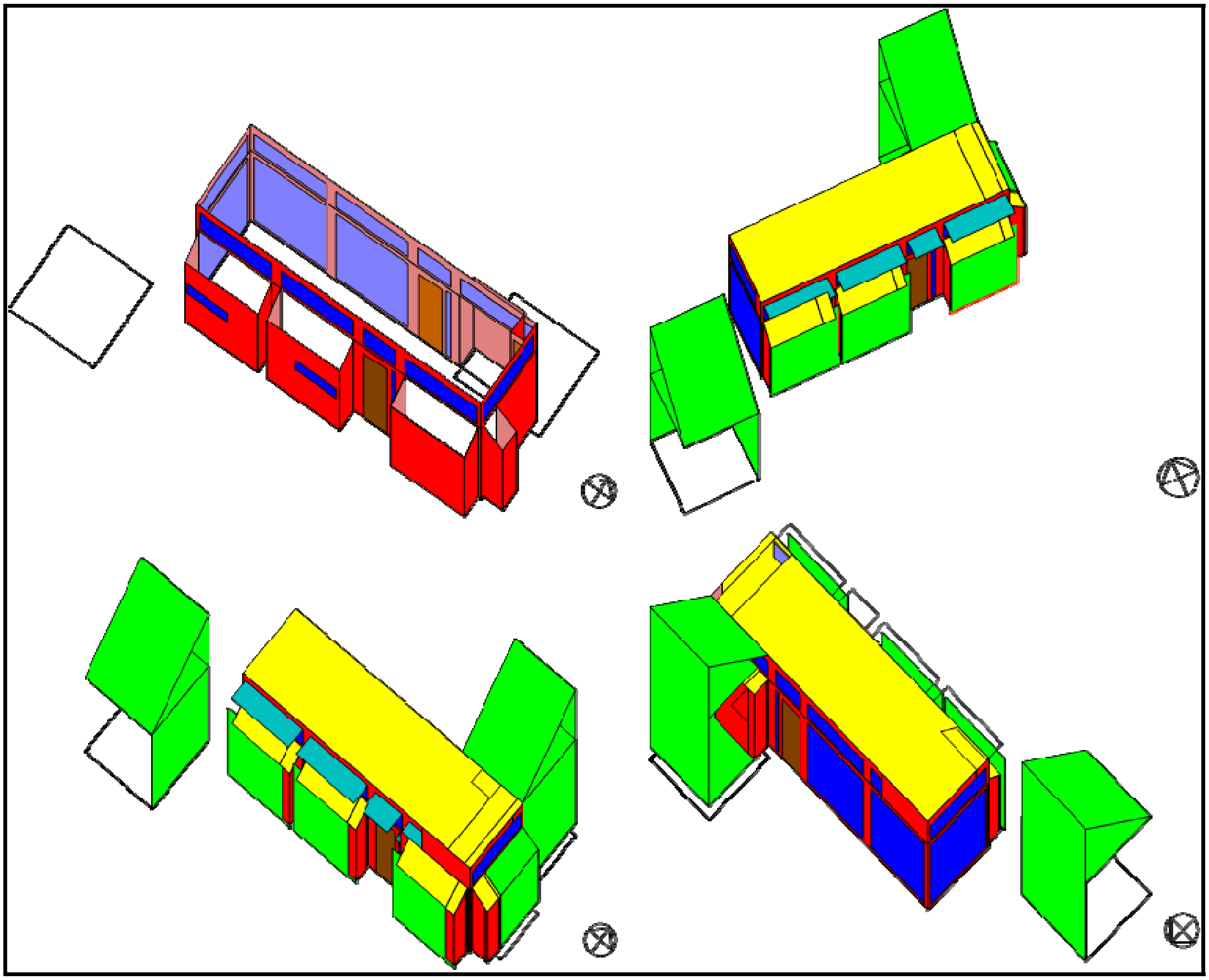


Figure 10: DrawBDL renderings of the TAMU house.

Section 3.3.2. Simulation for Energy Analysis

The energy analysis performed on the house consisted of an overall energy balance, which utilized the DOE-2.1e program (version 119), along with the WINDOW 5 program, the F-CHART and PV F-CHART programs as well as the RADIANCE, DAYSIM and ECOTECT program. Every change made on the house envelope and systems was accompanied with an adjustment of the energy analysis simulation. Figure 11, Figure 12, and Figure 13 show an evolution in the appearance of the simulated entry, beginning with:

- The appearance of the June 2006 Preliminary Engineering Analysis (Figure 11).
- The appearance of the November 2006 Comprehensive Energy Analysis Report (Figure 12).
- The final design that considered vertical south-facing solar thermal panels and high efficiency PV accompanied by Building Integrated Photovoltaic (BIPV) panels (Figure 13).

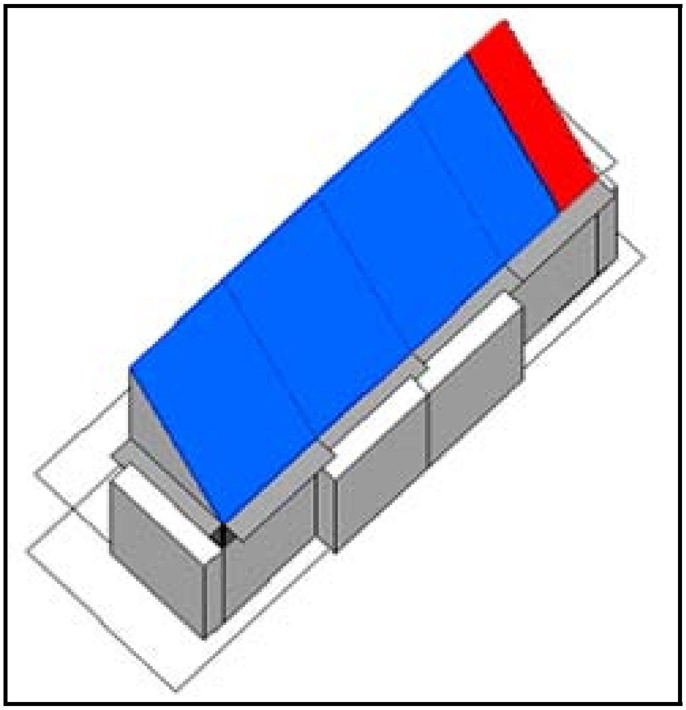


Figure 11: Preliminary design submitted in June, 2006 (Blue=PV panels, Red=Solar Thermal).

The overall analysis procedure for the simulation is shown in Figure 14. The basic tasks in the analysis included:

1. Simulation of hourly building electrical load for each scenario using the DOE-2.1e program with the proper weather files for three different climate zones (i.e., Sterling VA, Houston TX, and Phoenix AZ),
2. Simulation of monthly, average daily solar thermal production using F-CHART,
3. Simulation of monthly, average daily electricity production using PV F-CHART, and
4. Combining the DOE-2, F-CHART and PV F-CHART analysis into a comprehensive energy balance by comparing:
    a. the solar thermal production vs. required thermal loads, and
    b. the PV electrical production vs. required electrical loads.

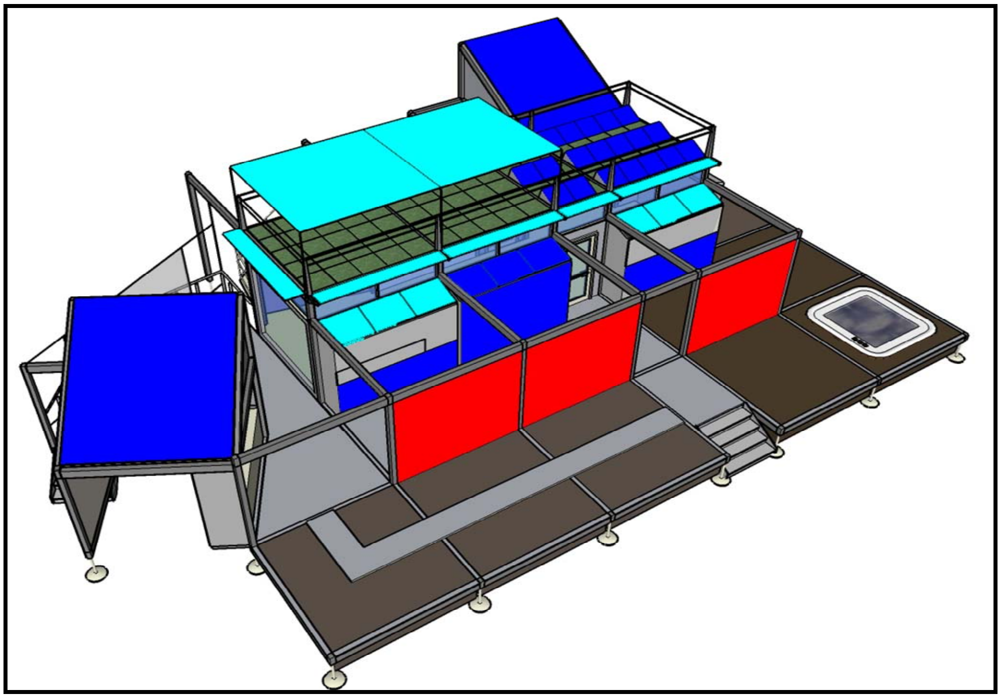


Figure 12: Design submitted in November, 2006 (Blue=High efficiency PV panels, Red=Solar thermal, Light-Blue=Low efficiency building integrated PV panels).

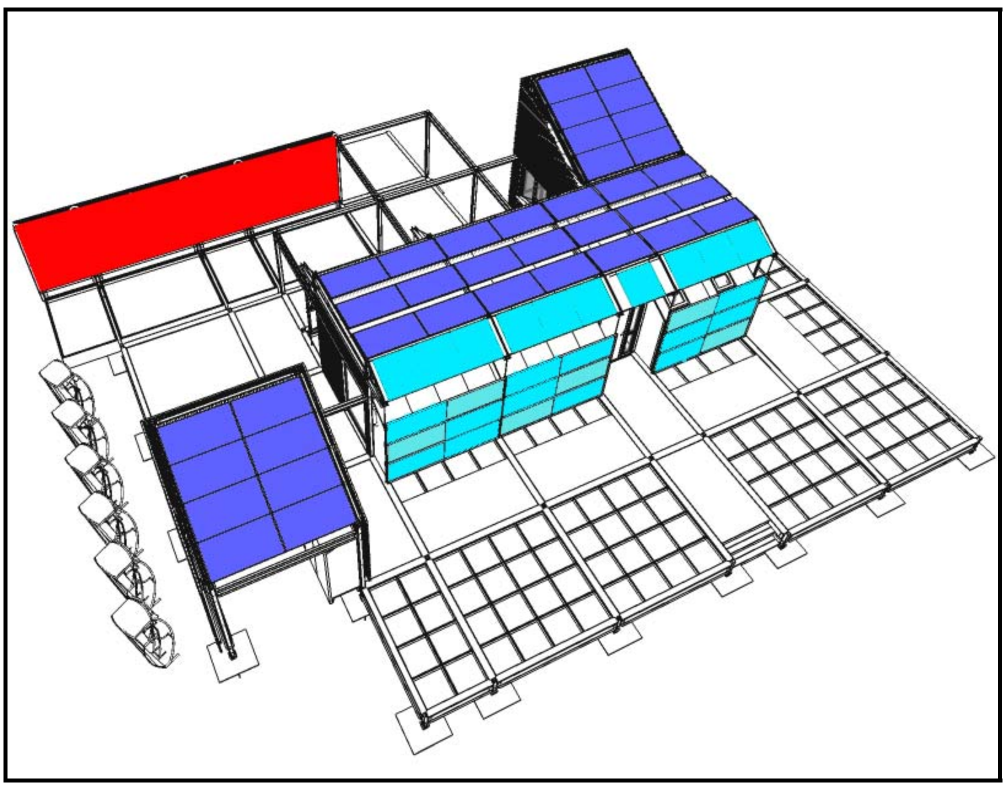


Figure 13: Final design submitted in August, 2007 (Blue=High efficiency PV panels, Red=Solar thermal, Light-Blue=Low efficiency building integrated PV panels).

In this fashion the energy analysis procedures used by the TAMU Solar Decathlon Team accomplished an integrated energy analysis with the goal of calculating an overall energy balance, which included:

- The DOE-2.1e program for simulation of the building energy use,
- The F-CHART program for analysis of the solar thermal energy production, and
- The PV F-CHART program for the analysis of the electricity production from the PV panels.

This combination of tools allowed a rapid, yet accurate estimation of energy requirements and the potential of energy production for many alternatives of the building and systems design. In addition, since the tools are regularly taught in several classes the students and the faculty had the knowledge to proceed immediately with the simulation in the early months of 2006.

DOE-2 Modeling Scheme

The DOE-2 modeling of the TAMU house was performed by Ms. Mini Malhotra. In the early stages of the design and modeling, the TAMU Solar Decathlon Team used a modular assembly of zones in DOE-2, which consisted of conditioned occupancy zones and service modules (gro-Walls). This allowed flexibility in analyzing different building forms and construction materials. The final design was modeled as a single zone served by a package system, since the spaces of the service modules effectively became part of the entire core.

The DOE-2 simulation input of the house included two switches that determine the building characteristics and operation:

1) Location: This switch simulated the house in three locations, namely, Houston, TX (hot and humid), Phoenix, AZ (hot-dry), and Sterling, VA (cold climate). Based on the climate (heating, cooling, and swing seasons) of these locations, this switch activates the system operation in heating/cooling mode, and interior shades for certain part of the year. Also, it determines the water mains temperature and affects the DHW use. The benchmark building envelope characteristics such as insulation level, infiltration, window U-value and SHGC are also affected by the location.

2) Model: This switch simulated the benchmark and the prototype house. This switch was incorporated to analyze the energy performance of the prototype house as compared with benchmark house in that location. This switch allows modifying energy-efficient improvements that include: efficient lighting and appliances, and construction characteristics, window area, and system efficiency. The Building America Research Benchmark Definition (updated December 15, 2006) was used for the analysis.

The use of these switches allowed rapid re-simulation of the evolving design at the (3) different locations.

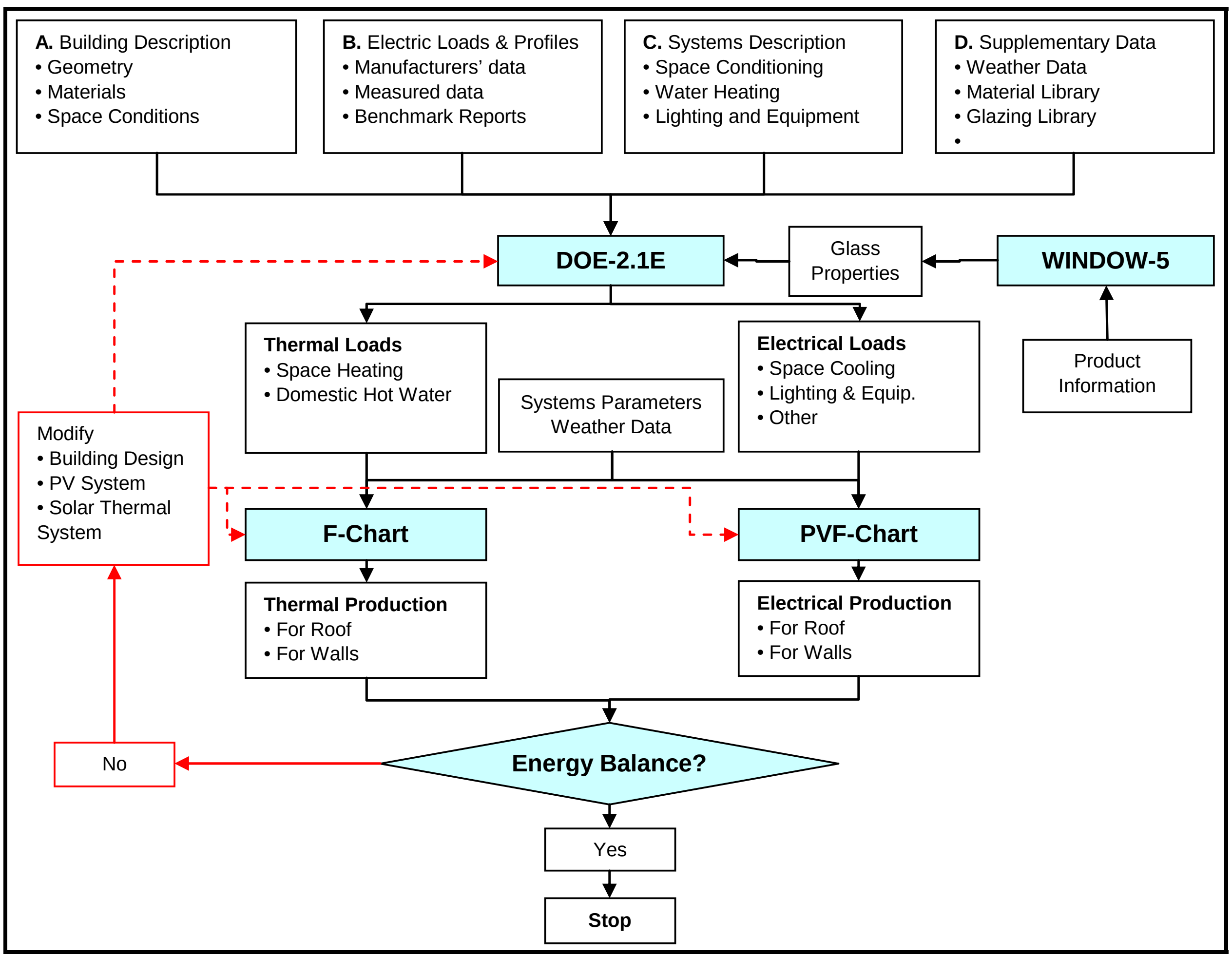


Figure 14: Flow chart of integrated energy analysis.

DOE-2 Simulation Results

From Figure 15 through Figure 17, the DOE-2 simulation results for the Houston, TX, Phoenix, AZ, and Sterling, VA, are shown. The upper left graphs of each figure show the monthly energy use, with the corresponding annual end-use proportions shown in the accompanying pie-chart. In the lower portion of each figure, the simulated daily energy use profiles are shown for a peak winter and summer day (January 4th and August 19th). The use of this type of simulated analysis from the DOE-2 program helped provide information about the diurnal energy needs of the house during the peak winter and summer days, as well as the annual energy requirements, which were then used as input to the design of the photovoltaic and solar thermal systems.

Annual Energy Use Summary

From Figure 15 through Figure 17 the results of the simulation for the three locations are shown. In the upper left portion of Figure 15, and Figure 18 (overall energy balance) the DOE-2 simulated monthly loads are shown that include DHW (23% annually), HVAC misc. loads (6%, including vent fans, pumps and misc.), cooling (18%), heating (18%), equipment (34%) and lighting loads (8%), with the corresponding annual end-use proportions shown in the pie chart. For the Houston, TX, location, the house is expected to consume 10,464 kWh/year, of which 6,050 kWh/year is electricity (no heating no DHW) and 4,414 kWh/yr for thermal loads including: DHW and space heating.

In Figure 16, the results of the simulation for the Phoenix, AZ, location are shown. In this same figure, (and in Figure 19) the upper left portion of the DOE-2 simulated monthly loads for DHW (18% annually), HVAC misc. loads (4% including vent fans, pumps and misc.), cooling (26%), heating (13%), equipment (28%) and lighting loads (7%) are shown, with the corresponding the annual end-use proportions shown in the pie chart. The analysis indicates that in the hot-dry climate (i.e., Phoenix), the simulated annual energy use is expected to grow to

11,574 kWh/year, of which 7,852 kWh/year is electricity (no heating no DHW), and 3,722 kWh/year for the thermal loads.

In Figure 17, the results of the simulation for the Sterling, VA, location are shown. In this same figure, (and in Figure 20) the upper left portion of the DOE-2 simulated monthly loads for DHW (25% annually), HVAC misc. loads (4% including vent fans, pumps and misc.), cooling (6%), heating (47%), equipment (28%) and lighting loads (7%) are shown, with the corresponding the annual end-use proportions shown in the pie chart. This indicates that in the cold climate (i.e., Sterling), the simulated annual energy use is expected to grow to 15,553 kWh/year, of which 5,099 kWh/year is electricity (no heating no DHW), and 10,127 kWh/year are for the DHW and space heating thermal loads.

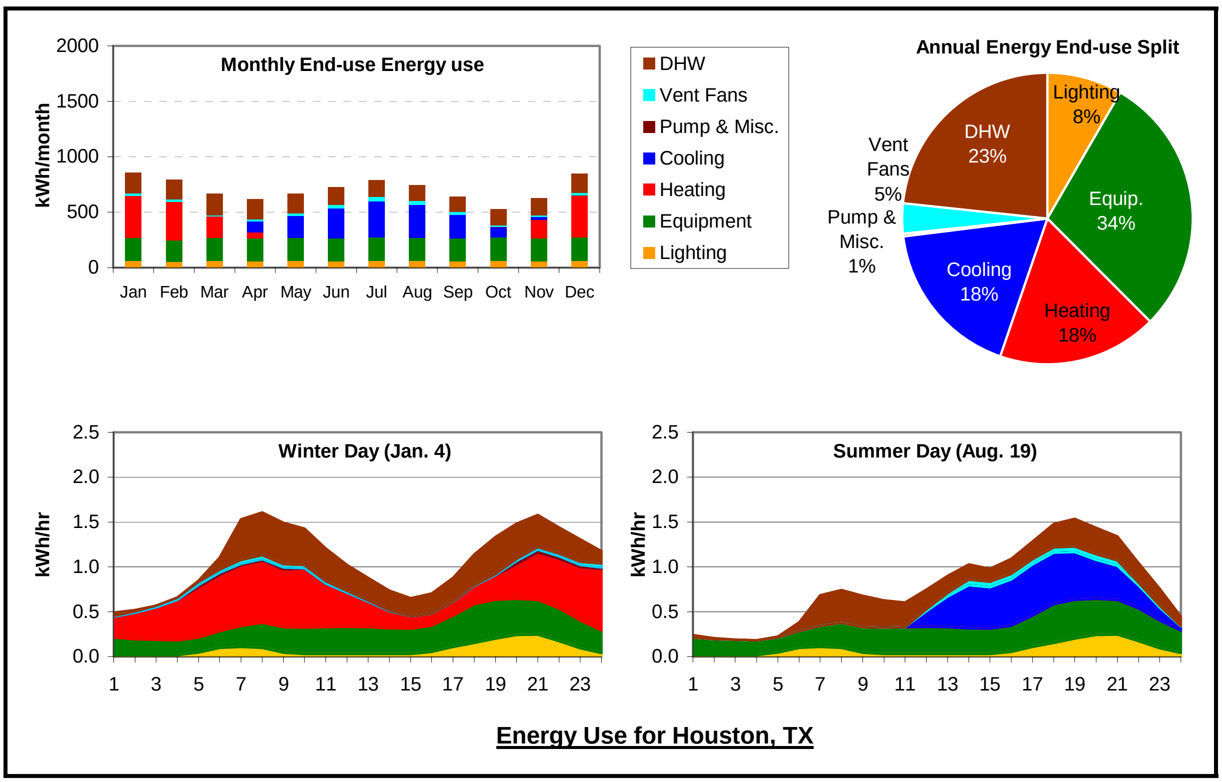


Figure 15: Simulated energy use for Houston, TX.

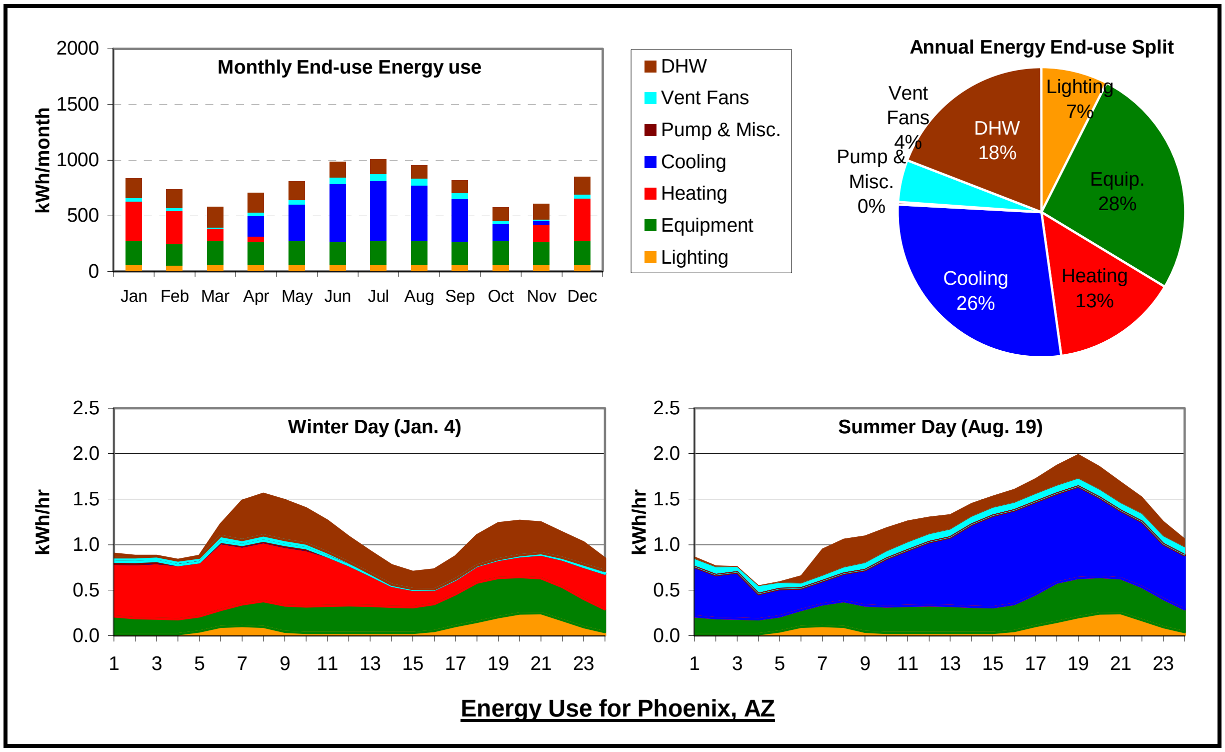


Figure 16: Simulated energy use for Phoenix, AZ.

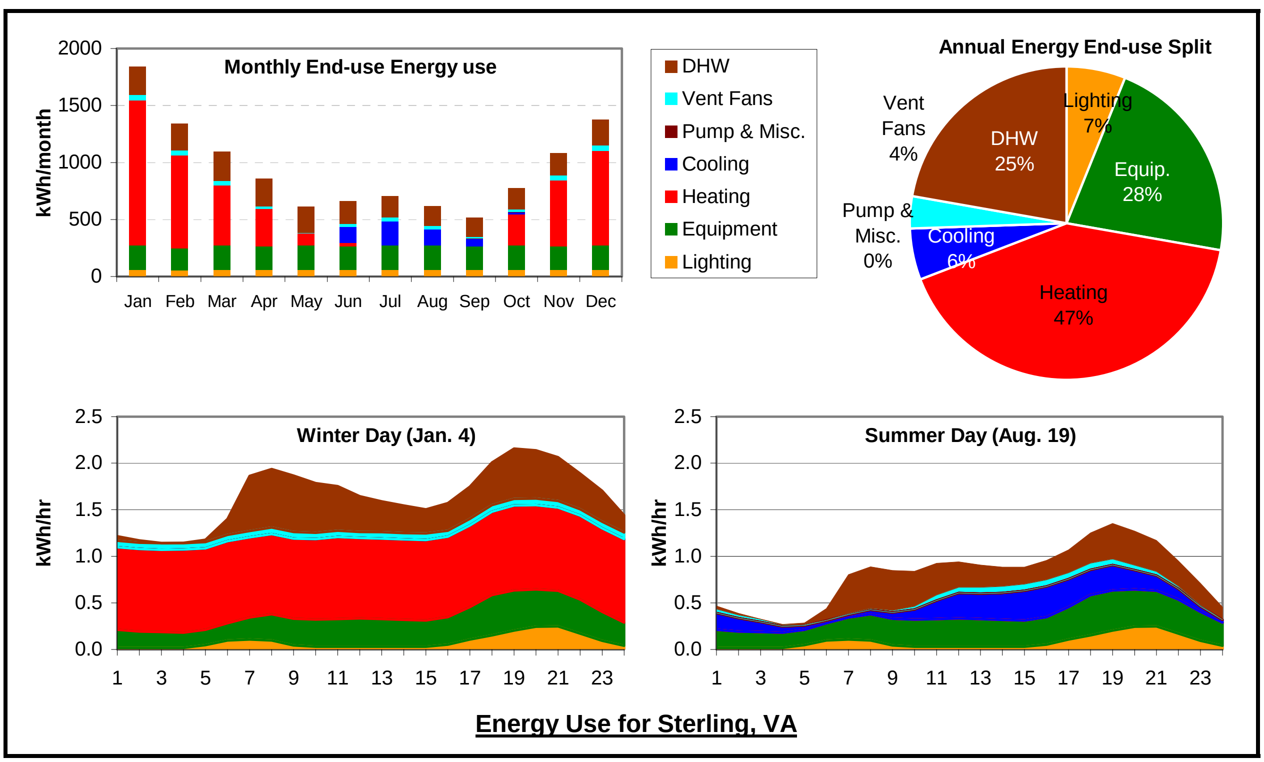


Figure 17: Simulated energy use for Sterling, VA.

Solar Thermal System Analysis

For the analysis of the solar thermal system the F-CHART software was used (Klein & Beckman, 1983). The analysis of the solar thermal system was performed by Soolyeon Cho. F-CHART is one of the most widely documented solar thermal analysis methods that use average daily monthly correlation that are based on hourly TRNSYS analysis (Haberl & Cho, 2004). The total thermal collector area used was 121 square feet (i.e., the aperture area of evacuated tube collectors), facing south and standing vertical (90 degrees) on the north side of the house facing south. Table 2 shows the input parameters used for the active solar system used (Figure 32) which had evacuated tube-type collectors (i.e., Apricus) and an atmospheric storage tank. For the evacuated tube collector, a test slope of 0.05 Btu/hr-sf-F, and an intercept of 0.42 were used for the F-CHART simulation. A collector flow-rate per area of 11 lb/hr-sf was used, which corresponds to a flow rate of 4.2 gallon per minute. The specific heat of the collector fluid was assumed to be 1 Btu/lb-F for water. Default values were used for the parallel and perpendicular incident angle modifiers. Table 3 shows additional data used for the simulation. Additional input and output files can be found in the appendix which includes the input parameters and output results for the Houston, Phoenix, and Sterling locations. For the input parameters, a value of 305 Btu/Hr-F was calculated for the UA from the DOE-2 simulation analysis. The daily hot water usage was estimated to be 26 gallons per day and an average environment temperature of 68F, both obtained from the DOE-2 analysis. Default values were used for all other system input parameters. For the output results, the first column (SOLAR) shows the amount of monthly solar insolation available for the respective site. The second and the third columns (HEAT and DHW) represent the monthly thermal energy needed to meet the space heating load and the Domestic Hot Water (DHW) load respectively. The (AUX) column indicates how much more energy is required in a month in cases where the proposed solar thermal system does not meet the total loads.

Table 2: Input parameters for the F-CHART simulation (system inputs).

	Input for System				
	Input	Units	HOUSTON	PHOENIX	STERLING
1	City call number		96	162	16
2	Water storage volume	Gallons	500	500	500
3	Building UA (0 for DHW only)	BTU/HR-F	305	240	333
4	Fuel (1=EL,2=NG,3=OIL,4=OTHER)		1	1	1
5	Efficiency of fuel usage	%	100	100	100
6	Domestic hot water (1=YES,2=NO)		1	1	1
7	Daily hot water usage	Gallons	26	24	29
8	Water set temperature	F	110	110	110
9	Environment temperature	F	68	68	68
10	DHW storage tank size	Gallons	204	204	204
11	UA of auxiliary storage tank	BTU/HR-F	7.6	7.6	7.6
12	Pipe heat loss (1=YES, 2=NO)		2	2	2
13	Inlet pipe UA	BTU/HR-F	5	5	5
14	Outlet pipe UA	BTU/HR-F	5	5	5
15	Relative load HX size		1	1	1
16	Collector-storage HX (1=YES,2=NO)		2	2	2
17	Tank side flowrate/area	LB/HR-FT^2	11	11	11
18	Heat exchanger effectiveness		0.5	0.5	0.5

Table 3: Input parameters for the F-CHART simulation (collector inputs).

	Inputs for Collectors				
	Input	Units	HOUSTON	PHOENIX	STERLING
1	Number of collector panels		6	6	6
2	Collector panel area	FT^2	20.2	20.2	20.2
3	FR*UL (test slope)	BTU/HR-FT^2-F	0.05	0.05	0.05
4	FR*TAU*ALPHA (test intercept)		0.42	0.42	0.42
5	Collector Slope	DEG	90	90	90
6	Collector Azimuth (South=0)	DEG	0	0	0
7	Receiver orientation (1=EW,2=NS)		2	2	2
8	Incident Angle Modifier (perpendicular)		1 .999 .998 .995 .981 .953 .882 .7 .35 0	1 .999 .998 .995 .981 .953 .882 .7 .35 0	1 .999 .998 .995 .981 .953 .882 .7 .35 0
9	Incident Angle Modifier (parallel)		1 .999 .998 .995 .981 .953 .882 .7 .35 0	1 .999 .998 .995 .981 .953 .882 .7 .35 0	1 .999 .998 .995 .981 .953 .882 .7 .35 0
10	Collector flowrate/area	LB/HR-FT^2	11	11	11
11	Collector Fluid Specific Heat	BTU/LB-F	1	1	1
12	Modify test values (1=YES, 2=NO)		2	2	2
13	Test Collector flowrate/area	LB/HR-FT^2	11	11	11
14	Test Fluid Specific Heat	BTU/LB-F	1	1	1

PV system Analysis

The analysis of the performance of the PV array was performed with the PV F-CHART software (Klein & Beckman, 1985). The analysis was performed by Piljae Im. In a similar fashion as the F-CHART software, the PV F-CAHRT analysis is also one of the most widely used solar analysis methods (Haberl & Cho, 2004). The system used in the TAMU house was analyzed for the same three locations mentioned before: Houston, TX, Sterling, VA, and Phoenix, AZ. For Sterling, VA, the Baltimore weather file was used for the simulation since the weather file for the specific location was not available for use with PV F-CHART. For each analysis, the efficiency, orientation, array slope array area, and azimuth were input for each group of panels. Table 4, Table 5, and Table 6 present the input parameters for each one of the different PV panels used in the simulated sites. Additional input values and output results for the PV-F-CHART runs are presented on the appendix. The input and output parameters are presented on a table. The input description is shown in the left portion of the table. The last two columns on the right show the results of each simulation. The values in the last column represent the monthly electricity production from the each group of PV arrays. The electricity production from each PV array group is summed up to calculate the electricity production from all PV arrays installed on the house.

Table 4: Input parameters for PV F-CHART simulation (HOUSTON, TX).

Input Parameters							
			HOUSTON				
	Input	Units	Suntech STP170 @ 0deg. Tilt	Suntech STP170 @ 25deg. Tilt	MSK Light Thru (24 cell)	MSK Light Thru (32 cell)	MSK Light Thru (40 cell)
1	City call number		102	102	102	102	102
2	Output (1=summary, 2=detailed)		1	1	1	1	1
3	Cell temperature at NOCT conditions	F	113	113	113	113	113
4	Array reference efficiency		0.133	0.133	0.055	0.073	0.09
5	Array reference tempereature	F	77	77	77	77	77
6	Max. power eff. Temperature coeff. (times 1000)	1/F	2.5	2.5	2.5	2.5	2.5
7	Eff. of maximum power oint tracking electronics		0.9	0.9	0.9	0.9	0.9
8	Efficiency of power conditioning electronics		0.88	0.88	0.88	0.88	0.88
9	Percent standard deviation of the load	%	0	0	0	0	0
10	Array area	FT^2	275	220	68	68	68
11	Array Slope	DEG	0	25	90	90	90
12	Array Azimuth (South=0)	DEG	0	0	0	0	0

Table 5: Input parameters for PV F-CHART simulation (Phoenix, AZ).

Input Parameters							
			PHOENIX				
	Input	Units	Suntech STP170 @ 0deg. Tilt	Suntech STP170 @ 25deg. Tilt	MSK Light Thru (24 cell)	MSK Light Thru (32 cell)	MSK Light Thru (40 cell)
1	City call number		168	168	168	168	168
2	Output (1=summary, 2=detailed)		1	1	1	1	1
3	Cell temperature at NOCT conditions	F	113	113	113	113	113
4	Array reference efficiency		0.133	0.133	0.055	0.073	0.09
5	Array reference tempereature	F	77	77	77	77	77
6	Max. power eff. Temperature coeff. (times 1000)	1/F	2.5	2.5	2.5	2.5	2.5
7	Eff. of maximum power oint tracking electronics		0.9	0.9	0.9	0.9	0.9
8	Efficiency of power conditioning electronics		0.88	0.88	0.88	0.88	0.88
9	Percent standard deviation of the load	%	0	0	0	0	0
10	Array area	FT^2	275	220	68	68	68
11	Array Slope	DEG	0	25	90	90	90
12	Array Azimuth (South=0)	DEG	0	0	0	0	0

Table 6: Input parameters for PV F-CHART simulation (Sterling, VA).

Input Parameters							
			STERLING				
	Input	Units	Suntech STP170 @ 0deg. Tilt	Suntech STP170 @ 25deg. Tilt	MSK Light Thru (24 cell)	MSK Light Thru (32 cell)	MSK Light Thru (40 cell)
1	City call number		20	20	20	20	20
2	Output (1=summary, 2=detailed)		1	1	1	1	1
3	Cell temperature at NOCT conditions	F	113	113	113	113	113
4	Array reference efficiency		0.133	0.133	0.055	0.073	0.09
5	Array reference tempereature	F	77	77	77	77	77
6	Max. power eff. Temperature coeff. (times 1000)	1/F	2.5	2.5	2.5	2.5	2.5
7	Eff. of maximum power oint tracking electronics		0.9	0.9	0.9	0.9	0.9
8	Efficiency of power conditioning electronics		0.88	0.88	0.88	0.88	0.88
9	Percent standard deviation of the load	%	0	0	0	0	0
10	Array area	FT^2	275	220	68	68	68
11	Array Slope	DEG	0	25	90	90	90
12	Array Azimuth (South=0)	DEG	0	0	0	0	0

Comprehensive Energy Balance Analysis

After the DOE-2 simulations and the PV F-CHART, and F-CHART analysis were run to determine the energy needs and available renewable energy each of the three cities, Houston, Phoenix, and Sterling, the monthly daily average results from the DOE-2, PV F-CHART, F-CHART analysis were then combined to the overall energy balance to see whether or not the anticipated loads were being met on an average day for each month, and whether or not extra electricity was available for charging the electric vehicle. Figure 18, Figure 19, and Figure 20 show the resultant balances of the houses in Houston, Phoenix, and Sterling. The month of October was also carefully inspected for the Sterling, Virginia, location as this month was the most representative of the conditions anticipated during the Solar Decathlon competition in Washington, D.C.

For the analysis, first, the monthly, electrical loads for the house were extracted from the DOE-2.1e output file. In addition to the loads from the DOE-2 simulation, an estimated electricity load required for solar thermal pumping was included as additional load. Next, the thermal load was calculated by adding the DHW load and space heating load. The remainder of the loads (i.e., lighting, equipment, misc., space cooling, and vent fans) were classified as electric loads. For Houston, as shown in Figure 18, the annual thermal load is estimated to be 4,414 kWh (42.2 % of total) and the annual electrical load is 6,050 kWh (57.8 % of total).

As a next step, the electrical load (i.e., no heating and no DHW loads) from the DOE-2 simulation was compared against the monthly PV electricity production. As shown in Figure 18, the electricity from PV meets the electrical loads for all months in Houston. Also, the building thermal loads were compared to the solar thermal production. As shown in Figure 18 for Houston, the house requires more thermal energy than the solar collectors can produce for six months (January to April and November to December). In this case the left-over from electric energy available from PV would be needed. After using the PV electric energy for the auxiliary thermal energy for space heating, which is left-over from total electric loads, three months

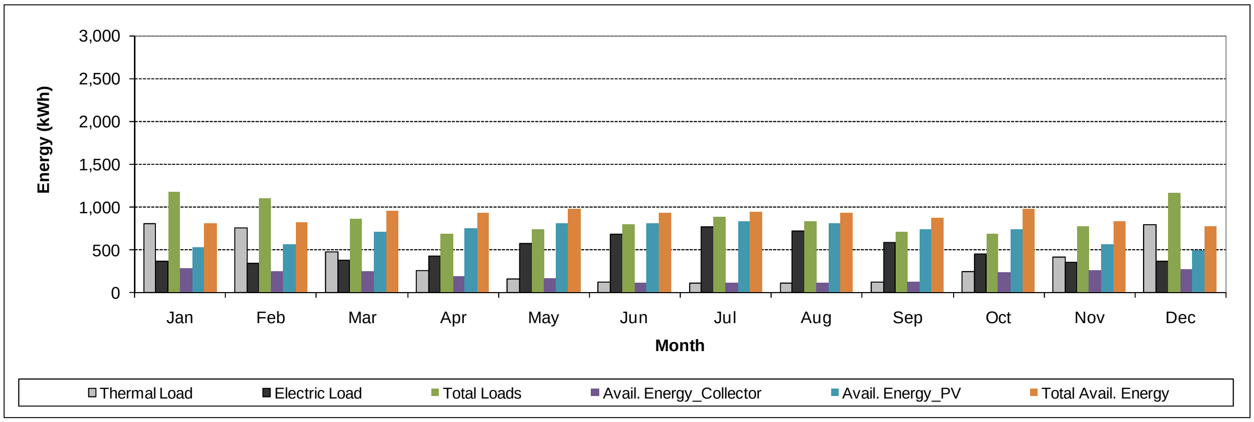
(January, February, and December) in the winter period will still require more energy for space heating, or space temperatures would need to be reduced.

The lower graph in Figure 18 shows the estimated miles/day to be driven by an electric car using the electricity left over after the estimated loads are met. Annually, the car can be driven from 0 miles to over 25 miles per day depending on the month in Houston.

In a similar fashion as the analysis for Houston, analyses were performed for cities for different climate conditions, as shown in Figure 19 and Figure 20. Using the Phoenix weather file, the annual thermal load is 3,722 kWh (32.2% of total load) and the annual electrical load is 7,852 kWh (67.8% of the total load). Using the Sterling weather file, the annual thermal load is estimated to be 10,127 kWh (65.1 % of the total) and the annual electrical load is 5,099 kWh (32.8 % of the total).

As shown in Figure 19, for Phoenix, the house meets the thermal and electric loads except for three months, July, August, and December, for which no electric energy will be available for the electric vehicle. And for the Sterling weather case in Figure 20, the electric car can be only used for summer months after meeting all the thermal and electric loads.

Energy Needed (from PS-E, DOE-2 output)												F-Chart	PV F-Chart	Total Energy Available
Month	Lighting	Equipment	Heating	Cooling	Pump & Misc.	Vent Fans	DHW	Solar Thermal Pumping	Thermal Load (Heating + DHW)	Electric Only (No Heating + No DHW)	TOTAL	Energy Available From Collector	Available Energy From PV	
	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh
Jan	52	224	626	0	4	66	183	23	809	369	1178	290	527.5	817
Feb	47	202	596	0	4	64	165	27	761	344	1105	254	569.2	824
Mar	52	224	307	37	3	40	173	27	480	383	863	250	712.3	962
Apr	50	217	102	101	1	40	152	27	254	436	690	190	746.2	936
May	52	224	25	205	0	67	140	32	165	580	745	165	812.6	978
Jun	50	217	0	289	0	92	122	32	122	680	802	122	816.9	939
Jul	52	224	0	351	0	109	118	32	118	768	886	118	834.5	953
Aug	52	224	0	316	0	99	118	27	118	718	836	118	811.9	930
Sep	50	217	9	221	0	71	123	27	132	586	718	132	738.1	870
Oct	52	224	102	107	1	42	141	27	243	453	696	243	734	977
Nov	50	217	262	35	3	35	154	23	416	363	779	272	569.4	841
Dec	52	224	622	0	5	66	174	23	796	370	1166	275	500.5	776
Yr	607	2640	2652	1662	21	791	1762	327	4414	6050	10464	2429	8373.1	10803



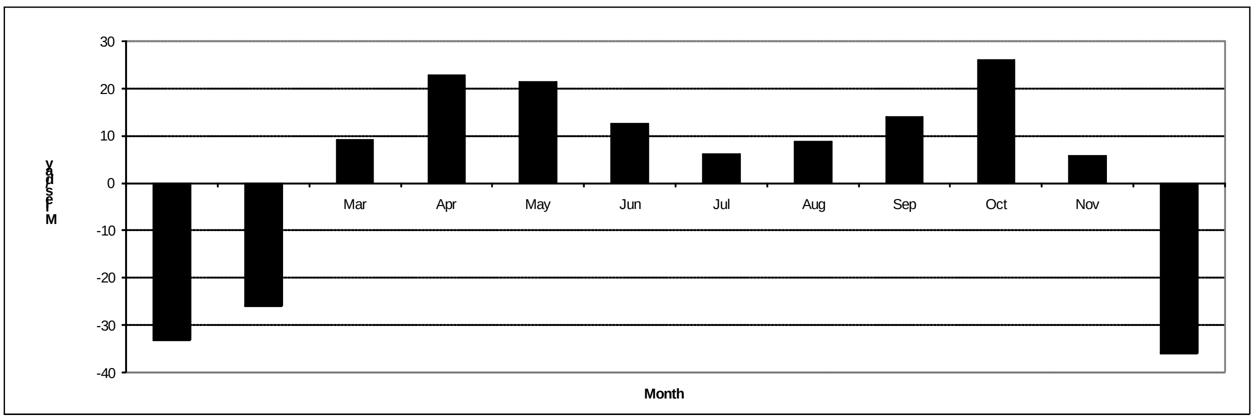
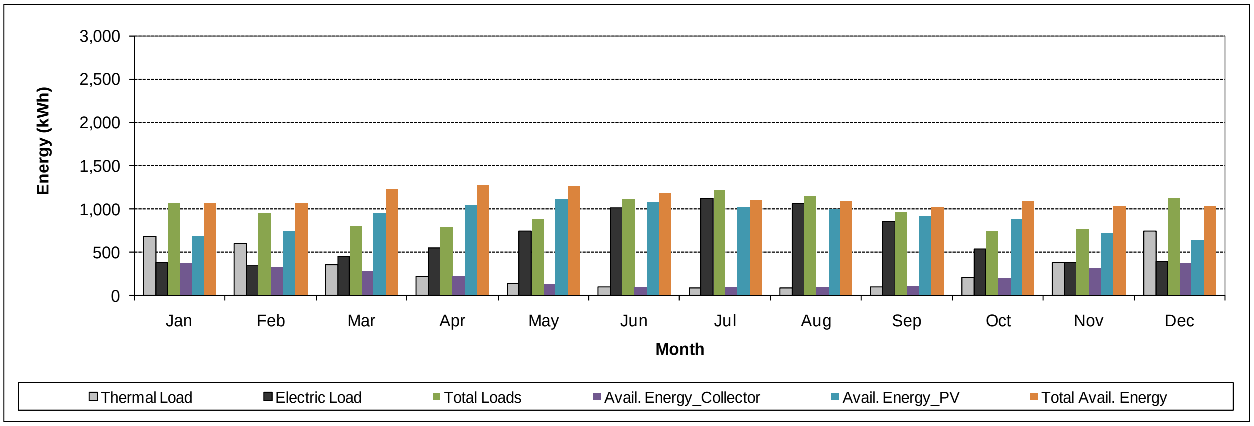


Figure 18: Combined DOE-2, PV F-CHART, and F-CHART results (Houston, TX).

	Energy Needed (from PS-E, DOE-2 output)											F-Chart	PV F-Chart	
Month	Lighting	Equipment	Heating	Cooling	Pump & Misc.	Vent Fans	DHW	Solar Thermal Pumping	**Thermal Load (Heating + DHW)**	**Electric Only (No Heating + No DHW)**	**TOTAL**	**Energy Available From Collector**	**Available Energy From PV**	**Total Energy Available**
	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	**kWh**	**kWh**	**kWh**	**kWh**	**kWh**	**kWh**
Jan	52	224	510	0	8	75	179	23	**689**	**382**	**1071**	**377**	**691.5**	**1069**
Feb	47	202	440	0	6	65	159	27	**599**	**347**	**946**	**329**	**743.2**	**1073**
Mar	52	224	192	88	2	58	162	27	**354**	**451**	**805**	**277**	**951.7**	**1229**
Apr	50	217	90	184	1	78	137	27	**227**	**557**	**784**	**227**	**1049.1**	**1276**
May	52	224	20	325	0	117	118	32	**138**	**750**	**888**	**138**	**1119.9**	**1258**
Jun	50	217	0	537	0	178	97	32	**97**	**1014**	**1111**	**97**	**1076.7**	**1174**
Jul	52	224	0	580	0	235	91	32	**91**	**1123**	**1214**	**91**	**1019.1**	**1110**
Aug	52	224	0	536	0	218	93	27	**93**	**1057**	**1150**	**93**	**994**	**1087**
Sep	50	217	0	403	0	161	103	27	**103**	**858**	**961**	**103**	**919.1**	**1022**
Oct	52	224	82	163	0	71	127	27	**209**	**537**	**746**	**209**	**881.6**	**1091**
Nov	50	217	237	44	2	47	145	23	**382**	**383**	**765**	**316**	**717.5**	**1034**
Dec	52	224	572	0	7	87	168	23	**740**	**393**	**1133**	**379**	**648.4**	**1027**
Yr	**607**	**2640**	**2144**	**2861**	**25**	**1390**	**1578**	**327**	**3722**	**7852**	**11574**	**2637**	**10811.8**	**13449**



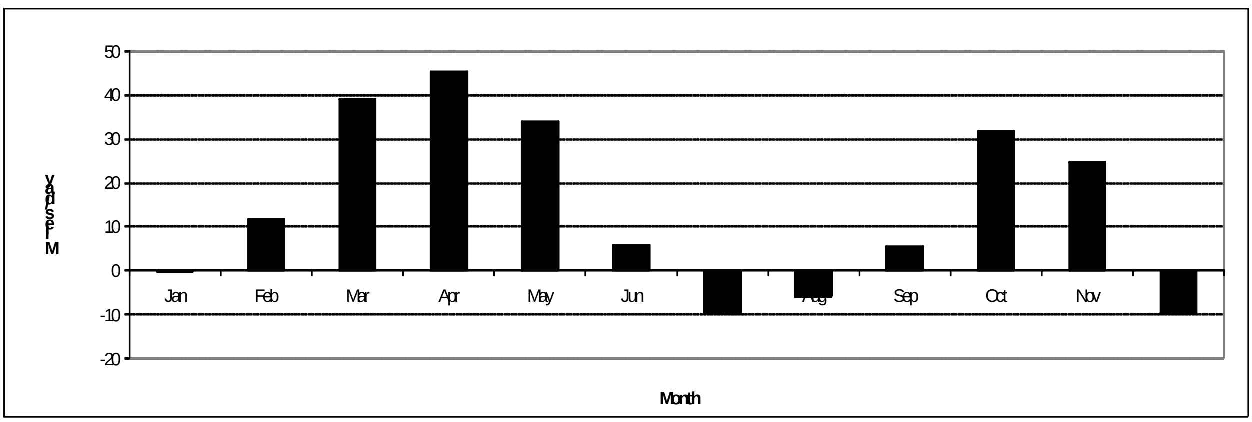
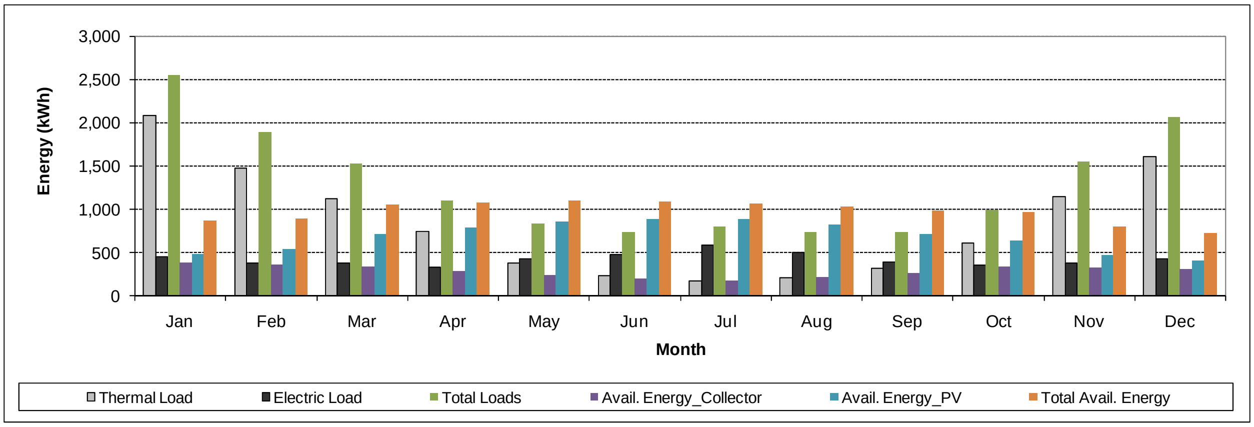


Figure 19: Combined DOE-2, PV F-CHART, and F-CHART results (Phoenix, AZ).

	Energy Needed (from PS-E, DOE-2 output)											F-Chart
Month	Lighting	Equipment	Heating	Cooling	Pump & Misc.	Vent Fans	DHW	Solar Thermal Pumping	**Thermal Load (Heating + DHW)**	**Electric Only (No Heating + No DHW)**	**TOTAL**	**Energy Available From Collector**
	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	**kWh**	**kWh**	**kWh**	**kWh**
Jan	52	224	1848	0	1	174	229	23	**2077**	**451**	**2551**	**393**
Feb	47	202	1271	0	3	131	210	27	**1481**	**383**	**1891**	**361**
Mar	52	224	897	0	8	101	226	27	**1123**	**385**	**1535**	**341**
Apr	50	217	545	0	6	57	206	27	**751**	**330**	**1108**	**289**
May	52	224	186	103	2	48	194	32	**380**	**429**	**841**	**241**
Jun	50	217	59	152	0	55	171	32	**230**	**474**	**736**	**210**
Jul	52	224	12	234	0	78	164	32	**176**	**588**	**796**	**176**
Aug	52	224	54	162	1	59	160	27	**214**	**498**	**739**	**214**
Sep	50	217	161	79	2	40	160	27	**321**	**388**	**736**	**267**
Oct	52	224	433	26	4	50	178	27	**611**	**356**	**994**	**334**
Nov	50	217	961	0	8	108	190	23	**1151**	**383**	**1557**	**330**
Dec	52	224	1398	0	4	154	214	23	**1612**	**434**	**2069**	**320**
Yr	**607**	**2640**	**7824**	**755**	**40**	**1055**	**2302**	**327**	**10127**	**5099**	**15553**	**3475**



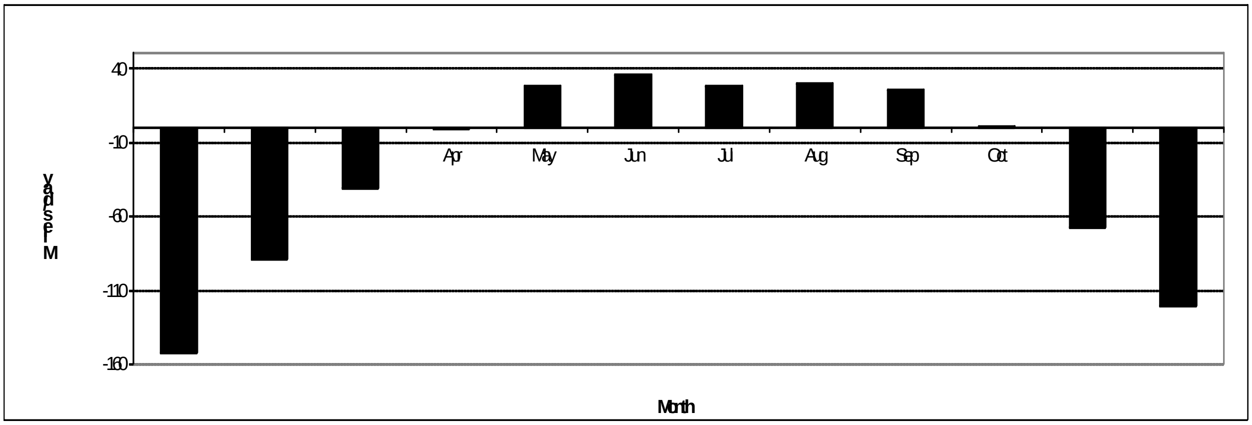


Figure 20: Combined DOE-2, PV F-CHART, and F-CHART results (Sterling, VA).

Section 3.3.3. Simulation for Daylighting Analysis

The gro-Home daylighting design was intended to provide visual comfort by maintaining the appropriate luminance and illuminance levels throughout the whole living space. The daylighting analysis of the house was achieved using a combination of tools and techniques, including: a cardboard scale model, High Dynamic Range (HDR) imaging, and computer simulation programs (Ecotect, Radiance, and Daysim). Simulations were performed for three specific days of the year: 21st of June, 21st of December, and 21st of October representing the yearly solstices and the approximate competition period. For the analysis, two models were constructed: a cardboard scale model and a computer model using Ecotect (Marsh, 2005). During the simulations, only the longitudinal hallway that involves the kitchen, the living area, the entrance, and the bedroom was considered in order to simplify both models.

Scale model

The examinations of the scale model involved two basic stages:
1) measuring illuminance values and
2) taking pictures at different exposure levels.

The illuminance values were measured at four specific locations inside the model. These locations were selected to represent the four basic spaces in the house that were considered during the simulations: 1) kitchen, 2) living room, 3) entrance and 4) bedroom. Using a sundial created with the Shadows (Blateyron, 2006) program, the examinations were made for two different locations: 1) College Station, TX, and 2) Washington, DC. By positioning the scale model with respect to the sundial, the measurements were made for the hours of 9:00 am, 12:00 pm and 4:00 pm on each of the three specific days of the year. Figure 21 shows an example of the positioning of the scale model with respect to the corresponding sundial. Table 7 and Table 8 present the illuminance level throughout the house for Washington, D.C. and College Station, respectively. Highlighted values in these tables show areas that needed redesigning since direct sunlight was hitting the space.

Figure 21: Team members working on the positioning of the scale model using the sundial; from left to right, Alaina Jones and Simge Andolsun.

After the measurements were completed with a light meter, a camera was placed in the east wall of the scale model (Figure 22) in order to take pictures at different exposure levels for each time and location mentioned before. Taking several pictures at different exposures levels allowed the team to generate the HDR images using the Photosphere (Ward, 2006) software. Figure 23 shows an example of one of the studied scenarios. The three pictures on the upper section are pictures taken at different exposure levels. The lower end picture illustrates the HDR image created with Photosphere. In order to see the comparison between the two models, Figure 23 should be compared with the Figure 24 which shows the model generated with Desktop Radiance (LBNL, 2003).

Table 7: Washington, DC Illuminance Levels

Washington, DC - Illuminance Levels (foot candles)							
Date	Space	9am		12 noon		4pm	
		Inside	Outside	Inside	Outside	Inside	Outside
21-Jun	1	226	9930	166	13800	172	8200
	2	296	9980	325	13640	414	8120
	3	342	9700	525	13700	548	8300
	4	585	9950	820	13360	5620	8700
21-Dec	1	177	4400	226	6500	240	2900
	2	415	4200	350	6300	350	2840
	3	425	4500	605	6200	440	2750
	4	590	4530	825	6180	544	2400
21-Oct	1	188	6270	190	8960	180	5000
	2	292	6460	350	9500	310	5200
	3	412	6510	505	9870	420	5010
	4	615	6620	740	10050	800	5000

Table 8: College Station Illuminance Levels

College Station - Illuminance Levels (foot candles)							
Date	Space	9am		12 noon		4pm	
		Inside	Outside	Inside	Outside	Inside	Outside
21-Jun	1	198	8600	126	12410	138	6500
	2	245	9400	244	12460	315	7600
	3	310	9310	324	12000	420	7000
	4	530	9190	630	12160	5500	7500
21-Dec	1	144	4500	195	7250	159	4500
	2	250	4400	275	7400	348	4350
	3	415	4350	437	7600	429	4360
	4	567	4380	560	7350	644	4370
21-Oct	1	154	5900	210	8900	105	3600
	2	245	5700	255	8860	265	4400
	3	360	5850	393	8580	352	4530
	4	516	5800	580	8900	690	4490

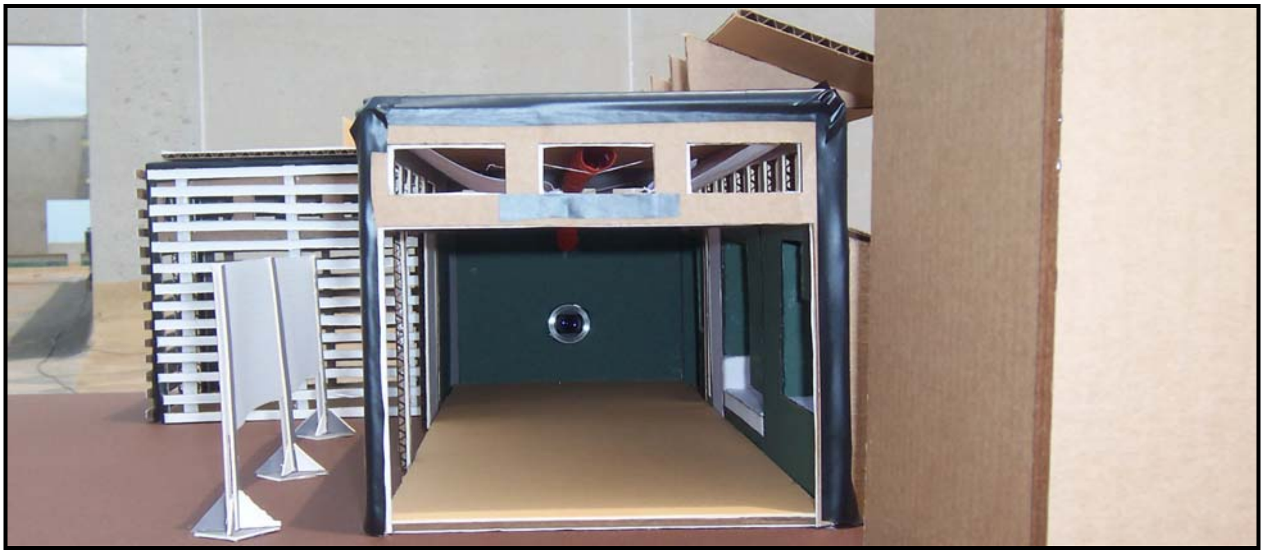


Figure 22: Wide angle camera lens at east wall.

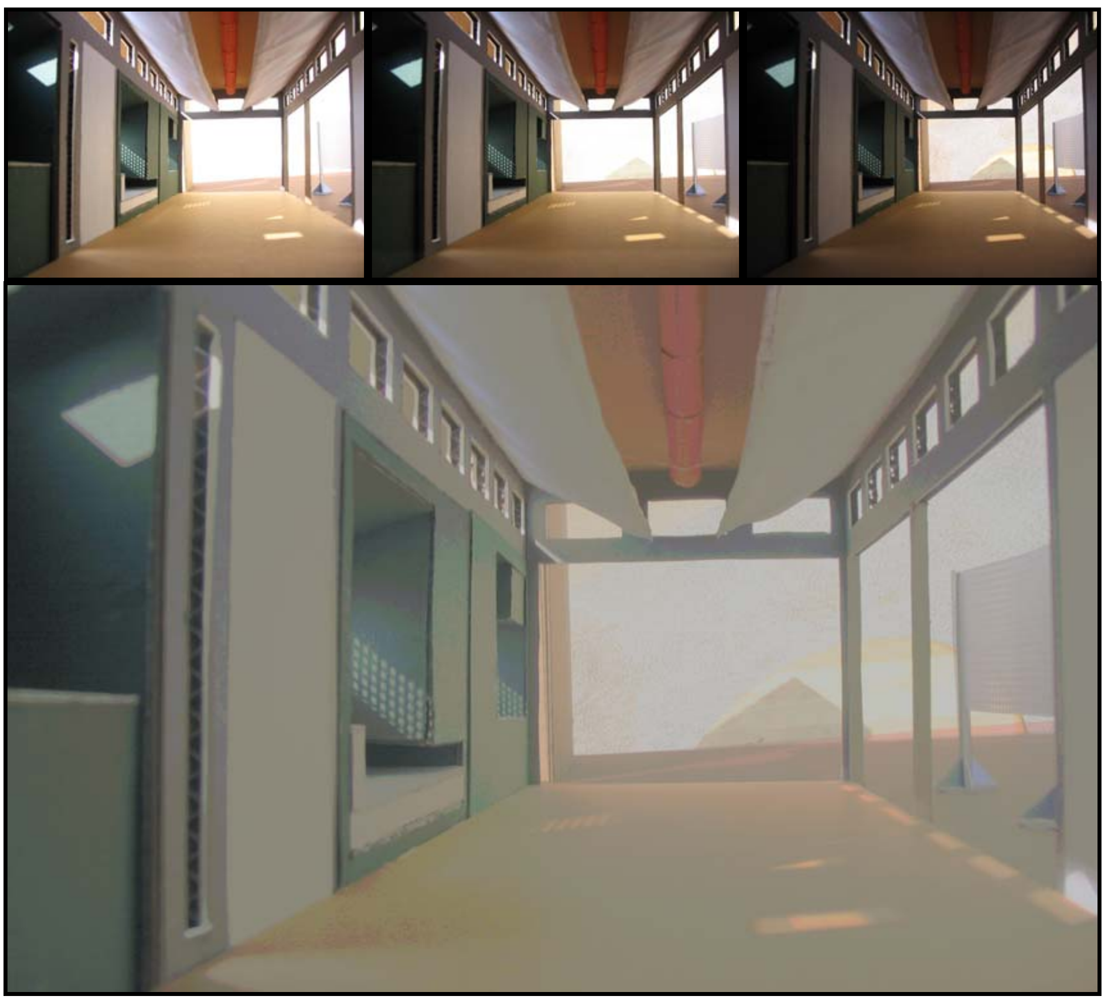


Figure 23: Washington, DC – October at 9:00am – Scale model photo images & HDR image.

Figure 24: Washington, DC – October at 9:00 am – Radiance image.

Ecotect Model

In addition to the scale model, the Texas A&M gro-Home was modeled in Ecotect, Radiance and Daysim (NRCC, 2006). Runs were completed using the respective input parameters. Since Radiance and Daysim runs were used for comparison to the scale model images and measurements, it was necessary to use measured weather files for College Station, TX, and for Washington, D.C. Unfortunately the appropriate weather files for each location of could not be easily obtained, therefore the weather file for Houston, TX, was used to represent College Station, and for Washington, D.C., the Nashville, TN, file was used. For greater accuracy, the latitude and longitude of Washington, D.C., were used with the Nashville, TN, weather file. A wide angle camera was placed in the Ecotect model having approximately the same view as the camera placed in the scale model.

Once the Ecotect model was complete with the materials selected, a camera in place and appropriate weather file, the model was exported to the Radiance control panel. Within the Radiance control panel four different images were generated, for each time and location condition; a raw image, human sensitivity image, false color image and contour line image. The complete Ecotect model was also exported into the Daysim control panel. Within Daysim, the annual illuminance levels were simulated, for both College Station, TX, and Washington, D.C., and the useful daylight index and daylight autonomy levels were obtained. Useful Daylight Index (UDI) is a dynamic daylight performance measure that determines when daylight levels are 'useful' for the occupant, i.e. neither too dark (<100lux) nor too bright (>2,000 lux). The UDI obtained levels can be seen in Figure 26 for Washington, D.C., and on Figure 25 for College Station, TX. On the other hand, Daylight Autonomy (DA) is the percentage of working hours when a minimum work plane illuminance is maintained by daylight alone. The DA levels are shown in Figure 28 for Washington, D.C., and on Figure 27 for College Station, TX.

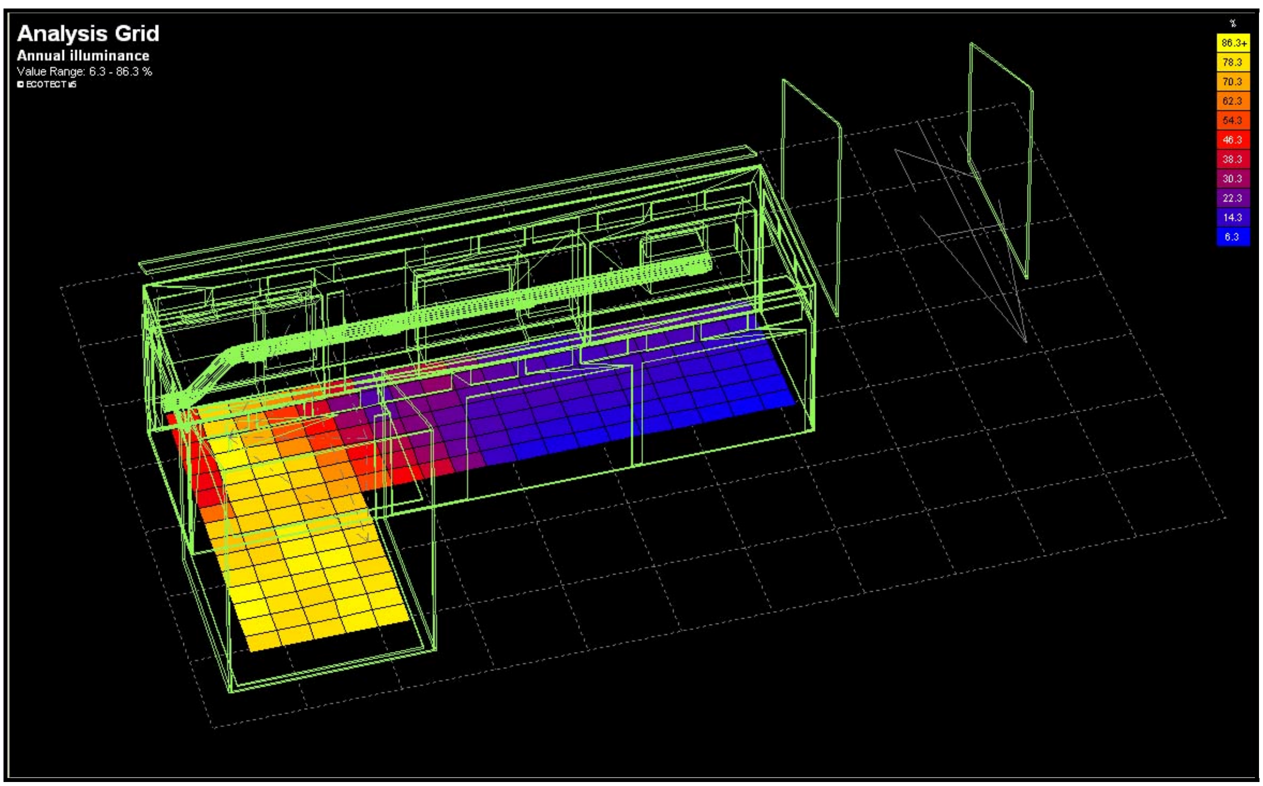


Figure 25: Useful daylight index (100-2000 lux) for College Station, TX.

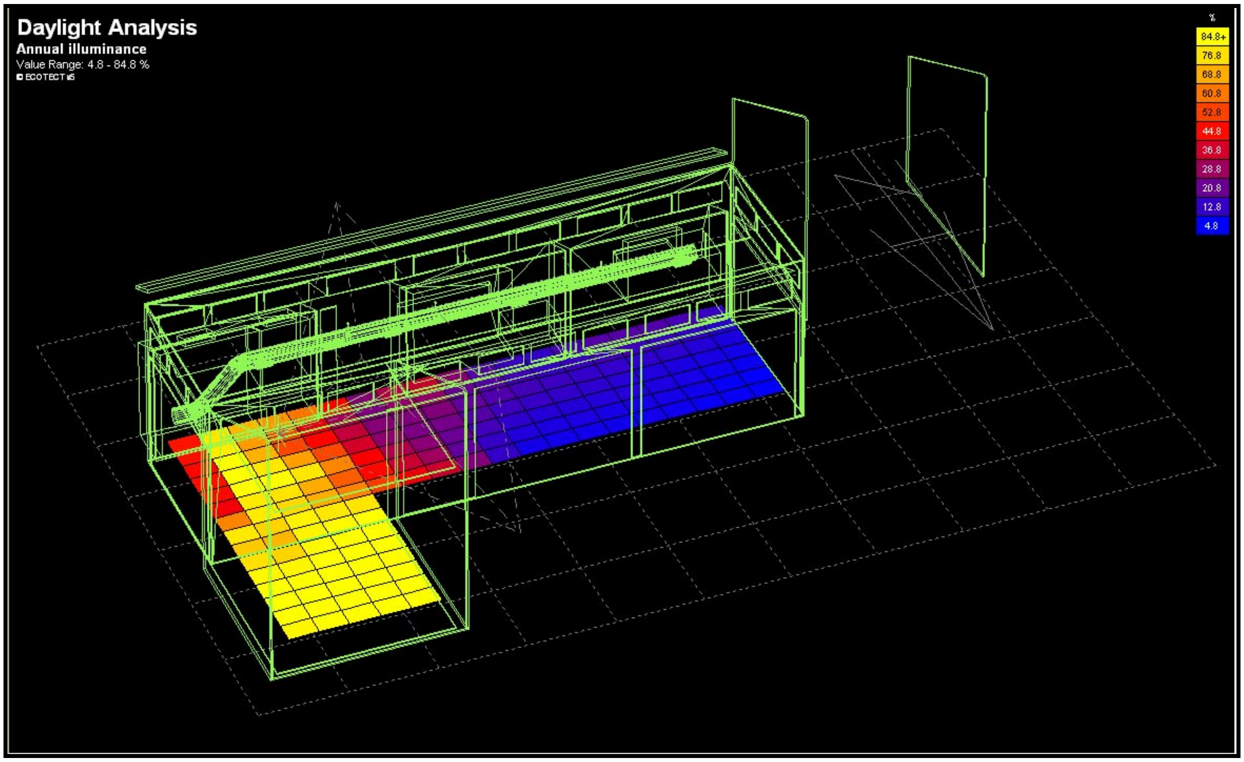


Figure 26: Useful daylight index (100-2000 lux) for Washington, D.C.

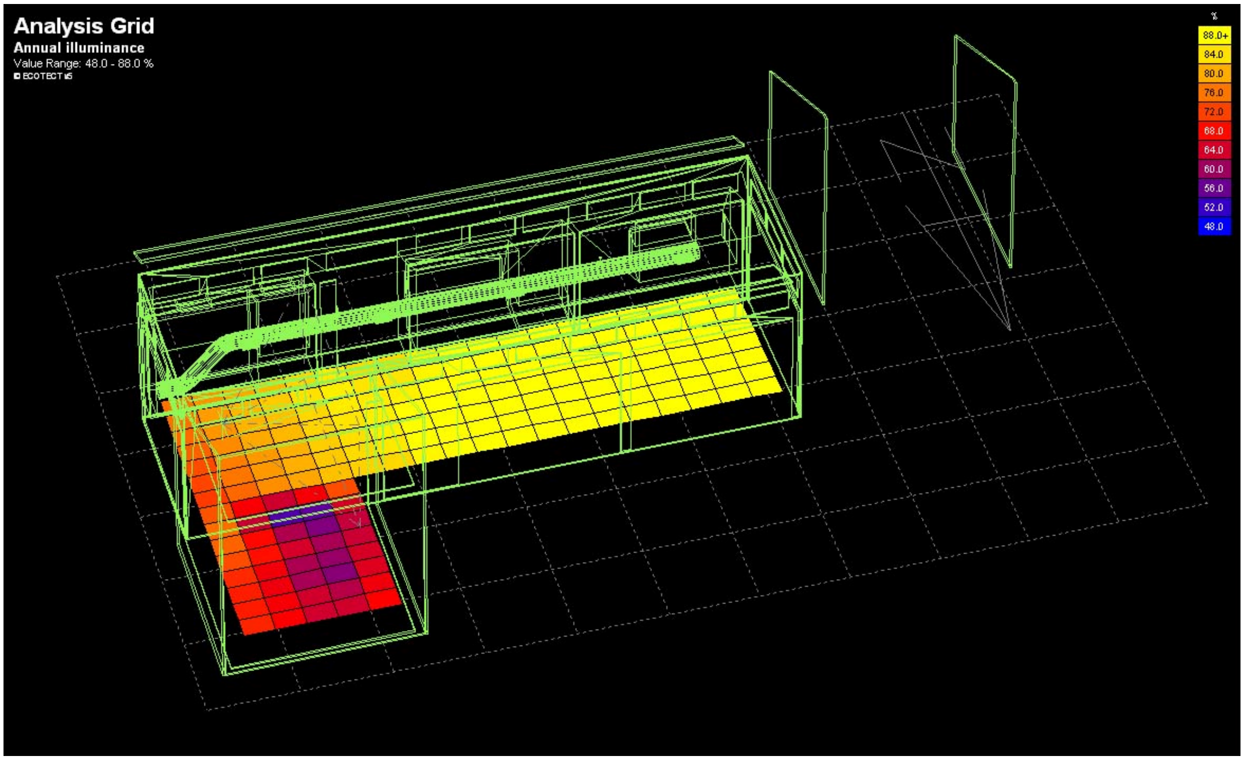


Figure 27: Daylight autonomy (at 300 lux) for College Station, TX.

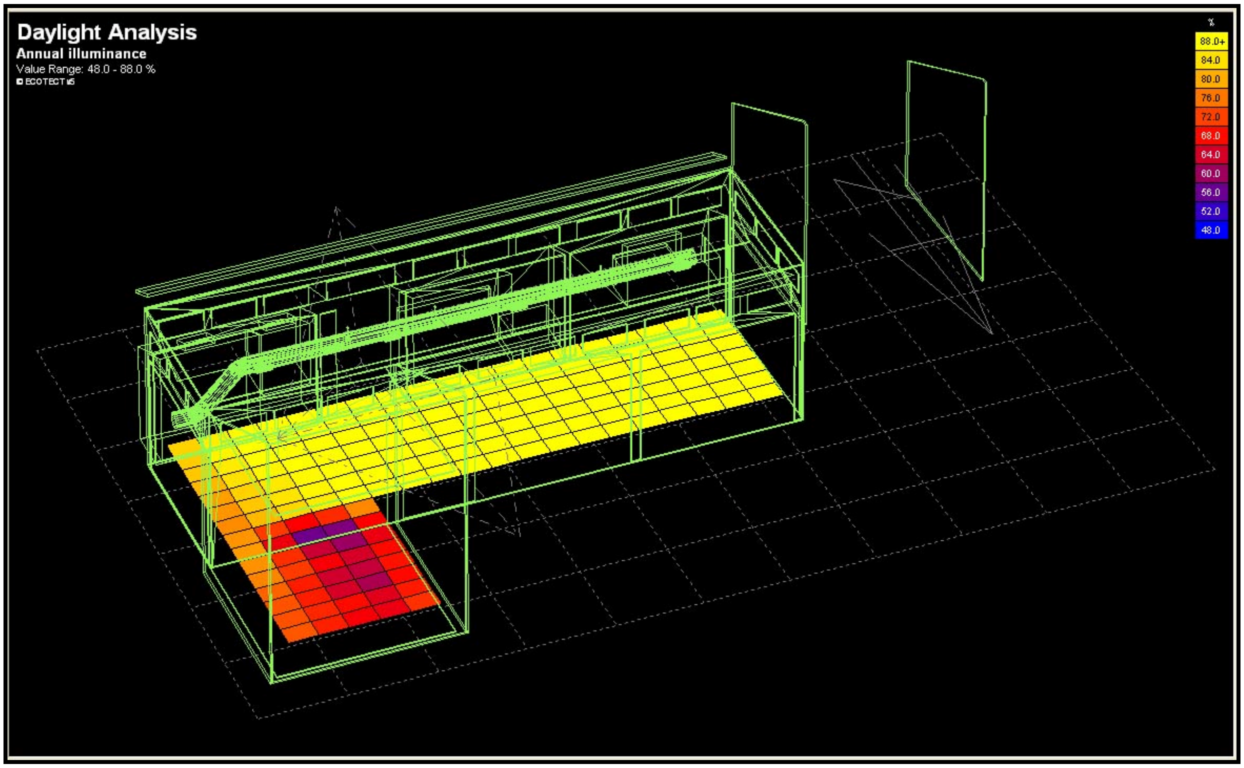


Figure 28: Daylight autonomy (at 300 lux) for Washington, D.C.

The day lighting simulation identified areas that needed redesigning such as the west and north façade where periods of direct sun light would provide an uncomfortable feeling for the resident. Based on the results obtained, changes were made in the design in order to have better control of the daylight coming into the space. Figures representing other simulation results can be seen in the appendix.

Section 3.3.4. M.E.P. Design and Appliances

Section 3.3.4.1. HVAC System Description

The Heating Ventilating and Air Conditioning (HVAC) system used in the house is shown in Figure 29. Figure 30 shows the components and locations of the HVAC system in the house. This system was specially designed to provide heating, cooling, and dehumidifying in addition to control the interior temperature and humidity, and the appropriate fresh air for the house. Special attention was also provided to assure quiet operation. The HVAC system needed to maintain the following conditions under all anticipated loads:

- Dry bulb temperature: between 68 and 76 °F
- Relative humidity: between 40 % and 55 %
- Noise criteria: below NC 25
- Air quality: at least 10% outside air plus air filter

The system consisted of a GE 1-ton Packaged Terminal Air Conditioner (PTAC) (with heat pump option) with the flexibility of using solar thermal energy for space heating. The integration of the solar thermal system with the HVAC system can be seen in Figure 34. The 120/240V PTAC unit was 24"(W) x 24"(D) x 32"(H), which fit easily into the HVAC gro-Wall located at the east end of the house. It had a Coefficient of Performance (COP) of 3.3. The unit was connected to a 10" round, galvanized steel, 35' long duct in the main core, with 4 registers staggered at locations in the house. A Trane Company Ductolator was used for the sizing of the duct layout. The balancing of the air flow coming out of the registers was manually controlled with dampers. The original 425 CFM fan in the HP was upgraded by the factory with a with a larger 500 CFM fan which provided more air flow. The larger fan was used because the unit was not usually used with over 8' of duct length and not more than one diffuser. The static pressure the fan needed to overcome was 0.4 inches of water. A special concern related with the ductwork was condensation during humid periods that required space cooling since the interior ducts were not insulated. The insulation of the ducts was recommended in order to prevent this from happening. However, due to aesthetic reasons the duct layout design included no insulation. Fortunately, the conditions that could have caused condensation never occurred during the competition. The unit provided both space cooling and heating. In the cooling mode, cooling was provided by the air conditioning cycle, which was powered by electricity from the batteries/photovoltaic system. In the heating mode, heat was provided by either the solar heating or the heat pump. The final stage of electric resistance heating in the heat pump was replaced with the solar heating by redirecting the signals from the thermostat. The unit included a solar heating coil, mounted above the heat pump, that utilized hot water from the solar thermal tank as the primarily heat source. When the system started in the heating mode, it first tried to heat the house using the solar heating, and then, if the solar heating was not able to fulfill the loads, the heat pump turned on to heat the house. During cloudy days when the water temperature from the solar thermal tank is not high enough, the system will operate as a heat pump and will use outside air as a heat source. In order to make this unit work in colder climates, when the water temperature in the solar thermal tank is not high enough, and the outside air is too cold (<25 deg F) for the heat pump to operate efficiently, modifications to the controls and the addition of an additional heat exchanger between the solar thermal tank and the heat pump might be needed. This will allow the heat pump to run more efficiently using the warm water from the solar thermal tank as a heat source.

A dehumidifier was also included to maintain the appropriate relative humidity levels. A 120V, 800W LG dehumidifier was used to maintain the indoor humidity level to a user defined level. The unit was an Energy Star, off-the-shelf, easy to control, compact unit [size: 15"(W) x 14"(D) x 21"(H)] that easily fits in the Edutainment (Educational and Entertainment) gro-Wall. Considering 40%-55% relative humidity (RH) a comfortable range, it was set at 55% maximum RH level. The automatic shutoff and restart system in this unit was supposed to enable it to operate only when needed.

An Energy Recovery Ventilator (ERV) was the source of clean and fresh air from the outside. A 120V, 85W Renewaire energy recovery ventilator was used to maintain a good air-quality indoors during occupied hours in an energy-efficient way. The unit provided fresh air to the house while minimizing the heating/cooling associated with extreme conditions. It allowed heat exchange between the exhaust air and the fresh air to preheat/precool the fresh air before being introduced indoors. This unit was 18"(W) x 11"(D) x 27"(H) and fitted easily into the HVAC gro-Wall. The ERV served as an independent source of ventilation that was manually controlled by the user depending on the interior conditions.

Similarly to every component and system in the house, the HVAC system passed through an evolution in the design process. The first system design excluded the use of an ERV and included two Variable Frequency Drives (VFD) (for the compressor and evaporator fan) and an Economizer composed of three dampers for the control of return and outside air flows depending on different conditions within the system. Unfortunately, the inclusion of these components made the control system too complicated requiring more sophisticated controls such as Programmable Logic Controllers (PLC) and programmable controllers from HVAC manufacturers. Multiple options were considered including the use of a mini-programmable controller. This idea was discarded due to the restriction of only having Underwriters Laboratories (UL) approved components. After re-analyzing the team's Do It Yourself (DIY) motto, the decision of going with a more simple system was taken. This was a major factor in the outcome of the competition and it is explained in the conclusions and recommendations section.

A brief summary of how the control system worked is presented in Table 9. The primary heating was provided by the hydronic heating coil connected to the solar thermal storage, assisted by the heat pump. Cooling and dehumidifying is accomplished with the normal operation of the air conditioning coil. In special conditions where dehumidification was needed, the dehumidifier was expected to turn on and dehumidify the space. An integration of the controls for the dehumidifier and the solar thermal space heating loop was necessary but never occurred because of the UL requirements. This was because the solar thermal heat exchanger location in the system was in the same location as a re-heat coil for dehumidifying purposes. This was also a factor on the Engineering subjective judging and will also be explained later in the report.

A diagram showing the air distribution system can be seen in Figure 31, where the supply air ducts are shown. The ductwork utilized appropriately designed diffusers to assure the proper throw and aspiration to achieve comfort conditions with minimum pressure drop. Impact isolation mounts were also used for the heat pump to reduce structural vibrations.

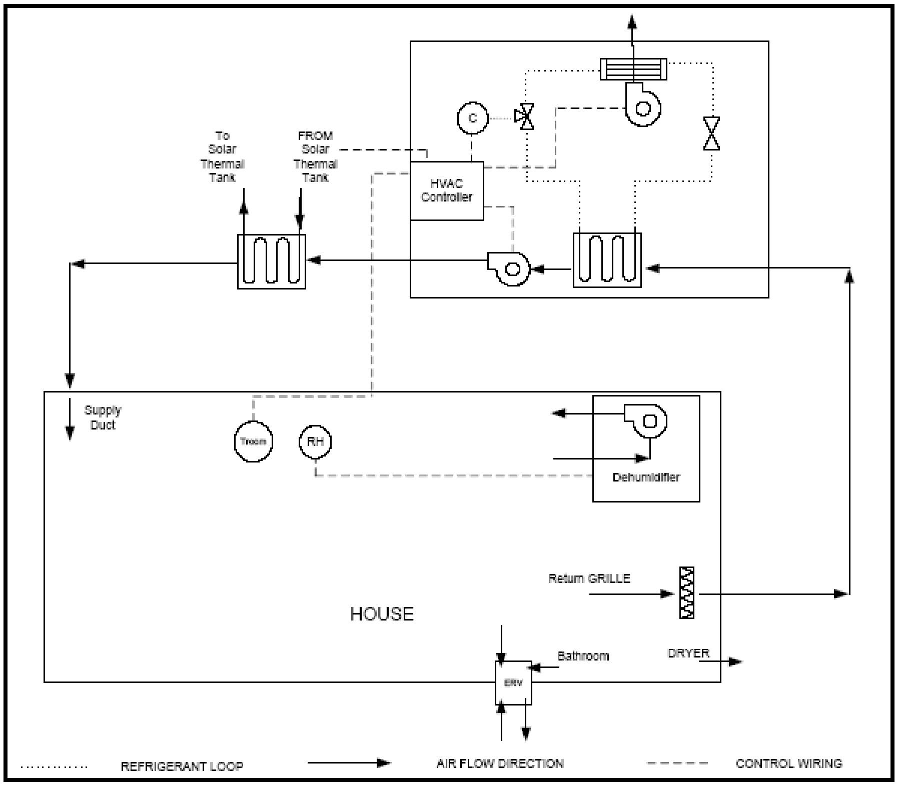


Figure 29: HVAC system schematic.

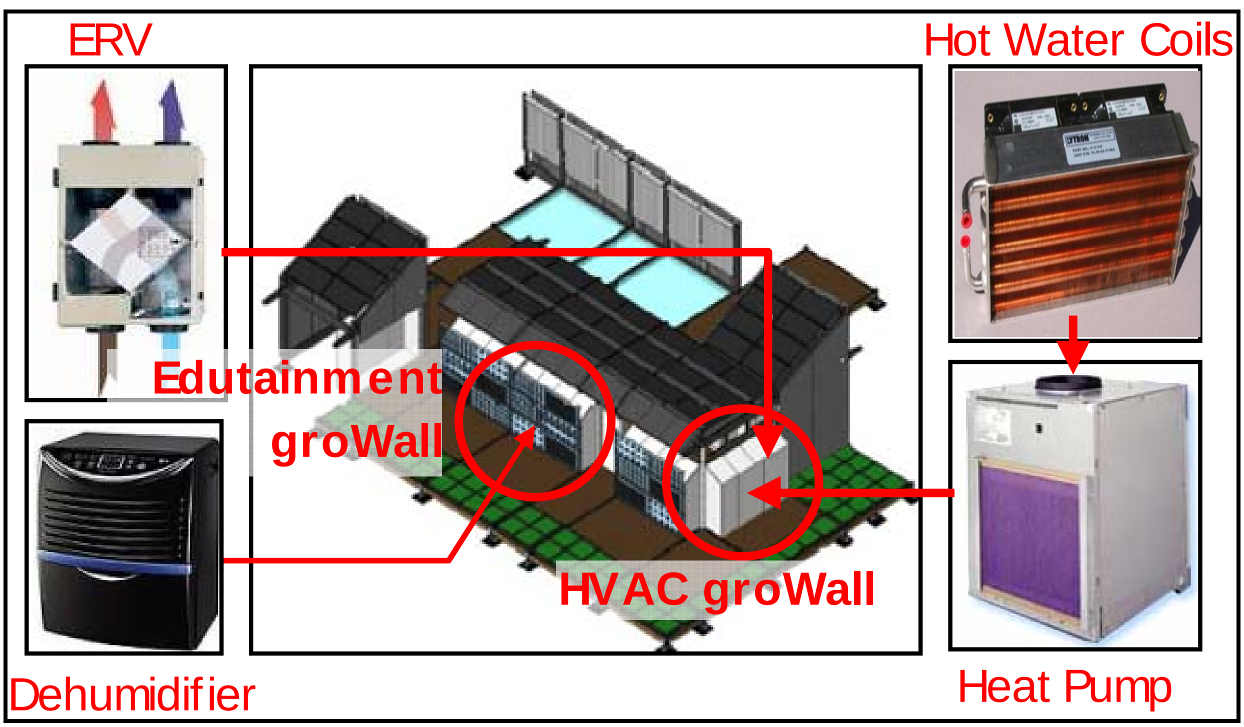


Figure 30: HVAC system components and their respective locations in the house.

Table 9: Control system modes and component operating per mode.

Mode	Component				
	Solar Heat Exchanger	Solar Heat Echanger Circulation Pump	A/C	Heat Pump	Dehumifier
Heat with solar heat exchanger	OFF	OFF	OFF	OFF	OFF
Heat with heat pump	ON	ON	OFF	OFF	OFF
Cool and dehumidify	OFF	OFF	OFF	ON	OFF
Dehumidify	OFF	OFF	ON	OFF	ON

Mode	Component				
	Solar Heat Exchanger	Solar Heat Echanger Circulation Pump	A/C	Heat Pump	Dehumifier
Heat with solar heat exchanger	OFF	OFF	OFF	OFF	OFF
Heat with heat pump	ON	ON	OFF	OFF	OFF
Cool and dehumidify	OFF	OFF	OFF	ON	OFF
Dehumidify	OFF	OFF	ON	OFF	ON

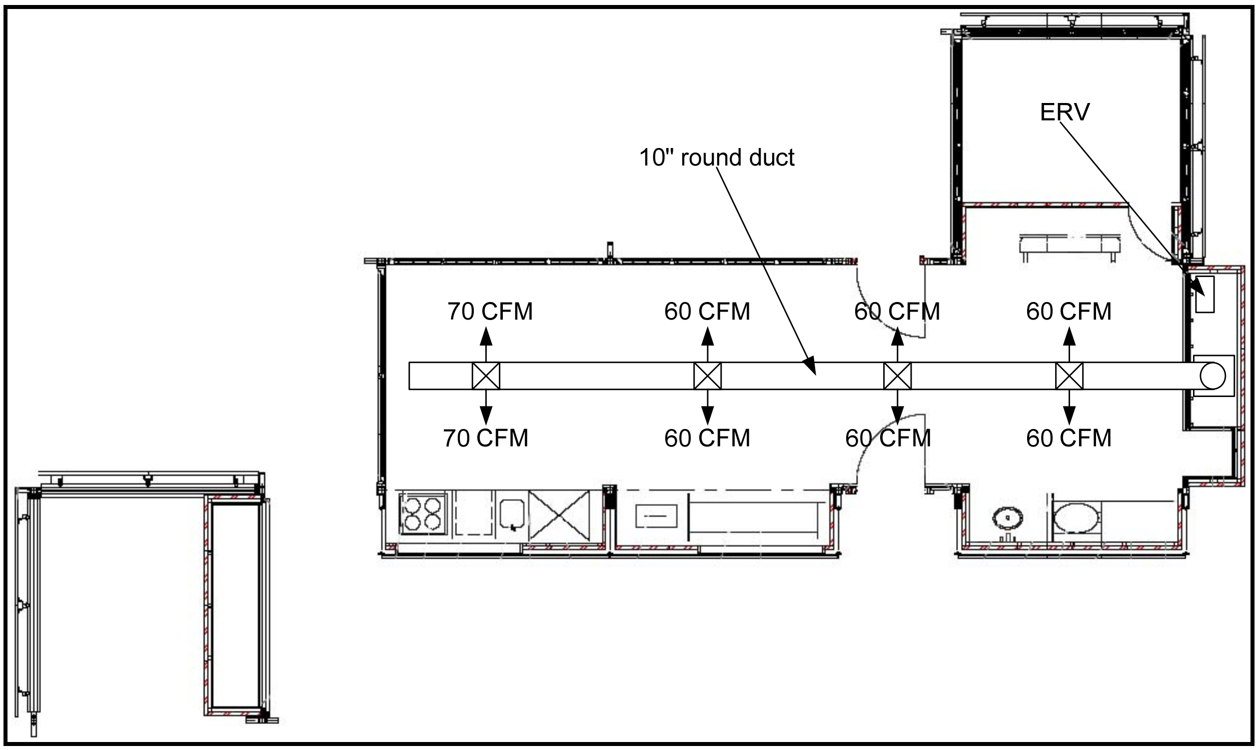


Figure 31: Supply duct schematic.

Section 3.3.4.2. Plumbing and Solar Thermal System

Figure 32 shows the diagram of the solar thermal system and the potable water distribution system. In the system diagram there are basically three water loops: two for the solar thermal system and one for the domestic water. In the first solar thermal loop, the water runs through the Apricus collector manifolds from the thermal storage tank and returns into the same tank, which was made of stainless steel surrounded by 3" of polyisocyanurate insulation (R-15). This tank was initially designed using fiber glass, however, due to cost issues it was replaced with a custom stainless steel tank. A Resol delta T (temperature difference) controller was used to control the Taco circulation pump for this loop. A sensor monitored the temperature of the thermal storage tank while another sensor monitored the temperature at the end of the last solar collector. The collector circulation pump ran whenever the collector temperature exceeded the tank temperature by 15 degrees (delta T). In addition, if the temperature of either sensor is higher than a maximum value (i.e., 180 °F) there was a control valve that modulated in order to redirect the water to a heat rejection unit avoiding overheating. The second loop was previously explained in the HVAC section. This loop consisted of using the energy from the solar thermal storage tank to heat the space. In this loop water was pumped from the solar thermal tank into the solar heat exchanger in the HVAC system, then, the water returned to the same tank. The third loop was for heating the domestic water. In this loop water was drawn from the supply tank through the supply pump, where it separated into the cold water supply and the hot water supply lines. The hot water supply then sent water into the heat exchanger in the thermal storage tank (i.e., coils of copper pipe). It then passed into two 7 gallon, 120V, 1500 W supplementary electric resistance heaters that supplied additional heat to continuously meet the desired set point temperature (i.e., 110 °F) for the hot water related tests (i.e. Hot Water and Appliances). These two Ariston water heaters were selected to assure that hot water was available for the competition. In the competition the largest use of hot water was the shower test, where 15 gallons of water had to be supplied for 5 minutes, maintaining an average temperature of 110 °F. To accomplish this, the Goulds supply pump was activated by a pressure drop in the system which was controlled with a pressure switch located at the impeller of the pump. This pump was connected to a 36 gallon pressurized tank in order to minimize the on-off cycling use of the pump. Components and locations for the first and third loop are shown in Figure 33. A combination of the three loops is presented in Figure 34.

The materials used for the water distribution lines were copper and cross-linked polyethylene (PEX). Copper was used for those portions of the loop where the temperature of the water could be higher than 140 °F since 140 °F temperatures are not recommended for PEX piping. These include the solar thermal loop and piping close to the solar thermal tank. For safety, only copper was use for pipes touching the solar thermal tank and a 10’ clearance was given before making any transitions to PEX. SharkBite fittings were used in every PEX-PEX and PEX-COPPER connections. This simplified the assembly and disassembly process of the plumbing system. On the other hand, the use of plastic bladder tanks for the supply and waste water tanks gave the team several setbacks due to their fragility. These bladder tanks where located on wood frames underneath the deck of the house. These frames were necessary to do the least damage to the grass of the National Mall.

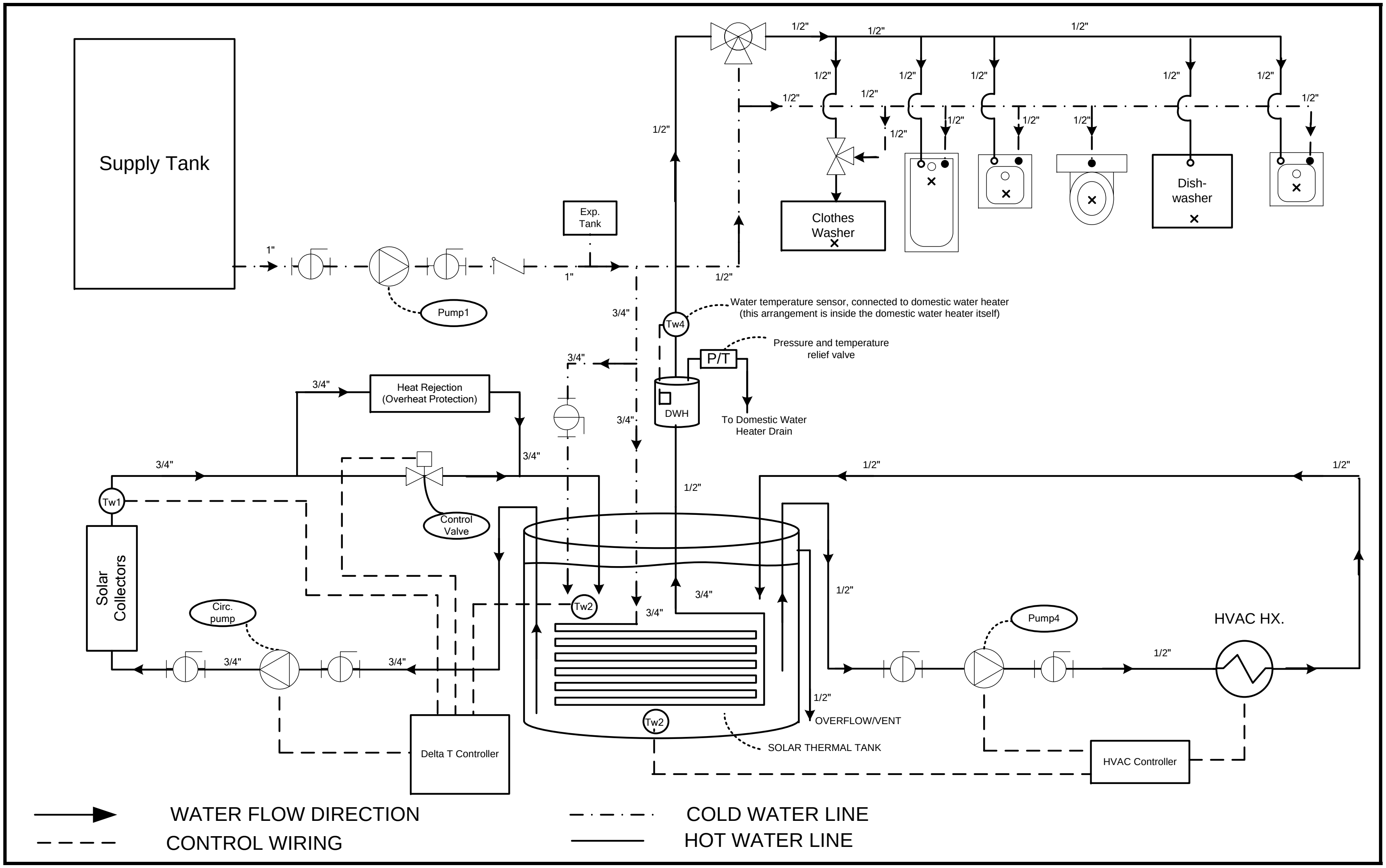


Figure 32: Plumbing and solar thermal system schematic.

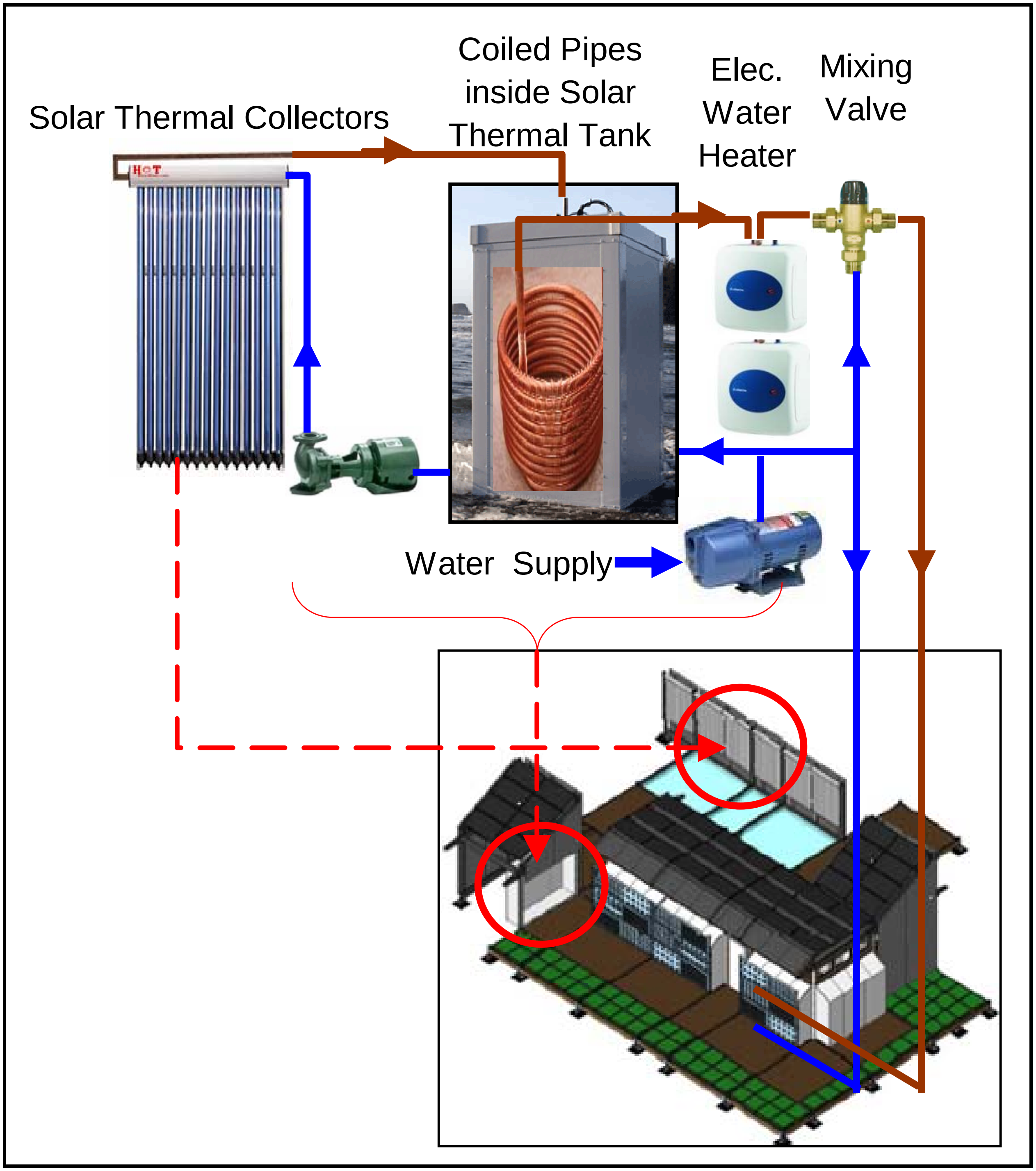


Figure 33: Location and components of the domestic water and solar thermal loops.

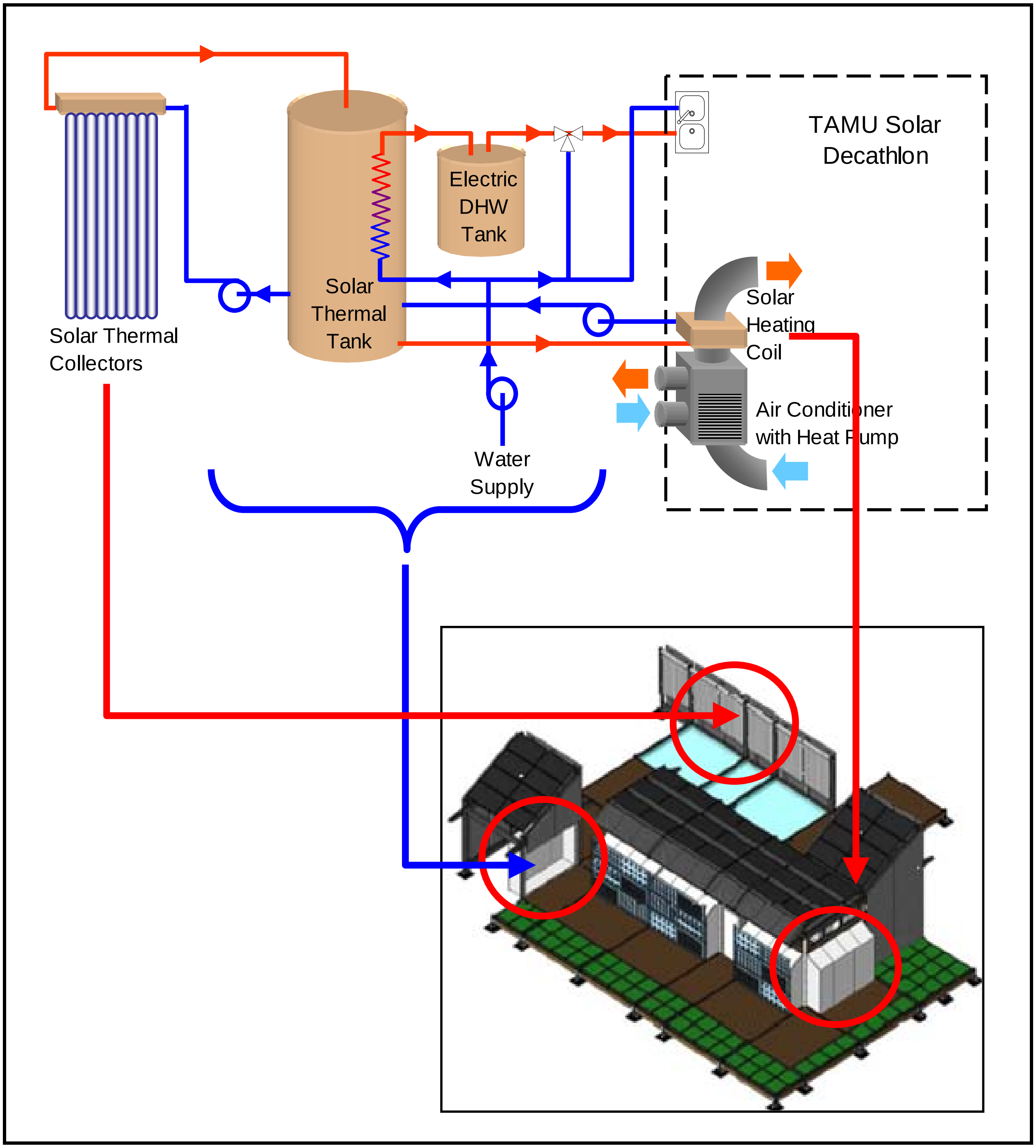


Figure 34: Location and components of the solar thermal loop and its integration with the solar heating coil.

Section 3.3.4.3. Appliances

Clothes Washer and Dryer

An ASKO clothes washer and dryer pair was chosen for the TAMU house. These are among the most energy-efficient products available on the market. The 120V clothes washer was a horizontal axis unit with an integrated electric resistance water heater, which consumes 133 kWh/yr electricity. (This includes energy consumed by 2000 W resistance heater for water heating). It uses only 9.3 gallons of water in a normal cycle (compared to 44 gallons in typical old-style agitators and 28 gallons in domestic front loaders). The modified energy factor is 2.5 (vs. 1.04 federal standards). The clothes washer was further modified by allowing the incoming water to be heated by the solar system, thus saving valuable electricity. The 240V clothes dryer has a 3000 W heating element. The clothes washer and dryer units were stacked to save the floor space and are compact enough to fit in the gro-Wall. The washer and dryer units and their house location are shown in Figure 35.

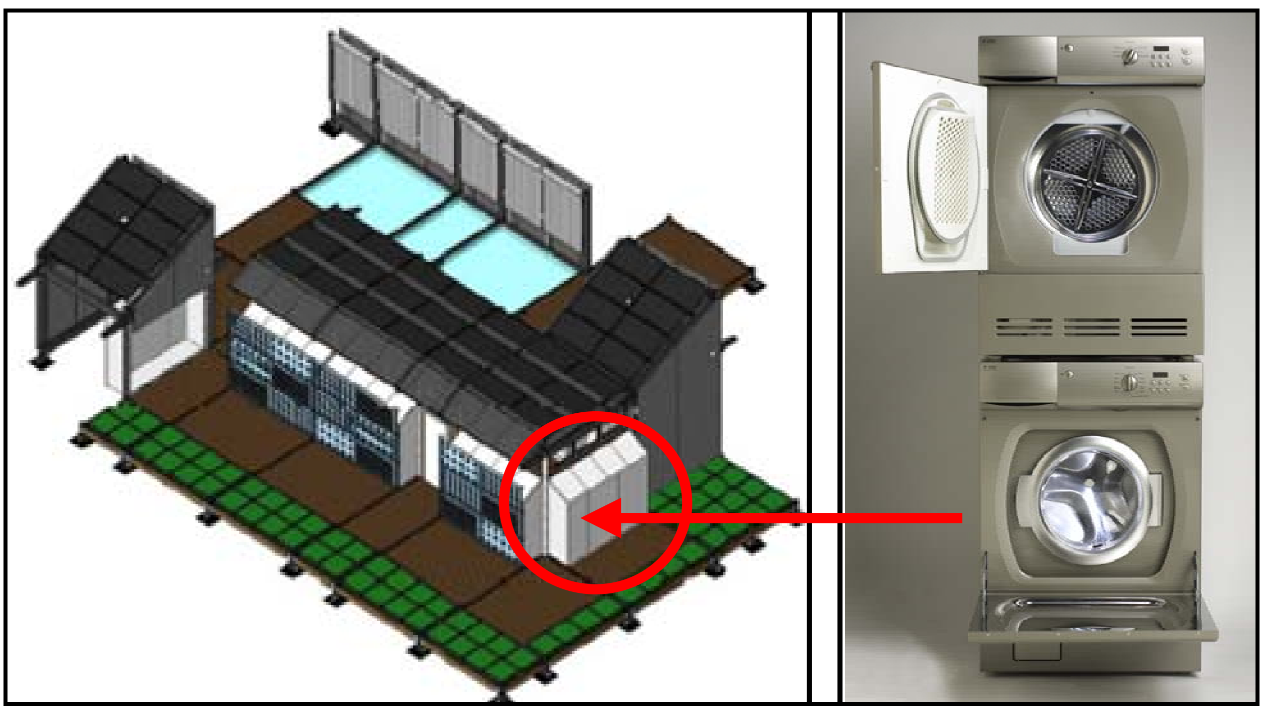


Figure 35: Washer and dryer units and their location inside the house.

Refrigerator, Dishwasher, Cook top and Microwave Oven

The kitchen appliances included a Subzero refrigerator/freezer, an ASKO dishwasher and a cook top and a microwave oven by Wolf. The Wolf appliances did not have the highest ratings for their efficiency. However, they were aesthetically pleasing and were easy to control. The cook top had an extractor fan which removed the cooking odors and humidity generated during the cooking tasks. The two-speed fan was located behind the back burners and exhausted the air underneath the house. The refrigerator/freezer used was not initially recommended since other units were more efficient such as the Sunfrost refrigerators/freezers. These Sunfrost refrigerators are more efficient but they do not maintain temperature as steady as the Wolf unit, which could lose points. The dishwasher was modified to receive hot water from the solar thermal loop. This minimizes the use of the electric heater located inside the unit. The units and their house location are shown in Figure 36.

Figure 36: Kitchen appliances used at the TAMU house.

Section 3.3.4.4. DC Electrical System Description

The photovoltaic (PV) system provided all the electricity required for the home plus electricity to run the electric car as part of the Getting Around contest. This off-grid system consisted of two parts; the PV solar arrays and the balance of system (BOS).

The solar arrays included roof-mounted PV panels (i.e., 36 Suntech STP170 panels) and wall-mounted light-thru panels (i.e., 18 MSK Light-Thru panels). There were three different types of light-thru panels on the TAMU house, each with a difference in the density of the cells in each panel. The panels with the lower density of cells were placed in front of the south facing gro-Wall windows with the intention of permitting more daylighting into the interior space. An array of Building Integrated PV panels provided shading to the south facing clerestory windows that also produced energy. Unfortunately, this array was not implemented because it was too heavy for the designed structure. Fortunately, the lack of these panels did not affect the power generation of the house since they were inefficient but it affected the daylighting performance and the thermal loads on the house. The total number of solar panels used was designed from an analysis of the daily and peak electricity needs for the house. Figure 37 shows the distribution of PV panels through the house. The rated DC kW of the total array was approximately 7.5 kW; assuming clear day conditions (1000 W/m^2). The specifications of the PV panels can be seen in Table 10.

The main components of the BOS were the charge controllers (i.e., 4 Outback MX60), the inverters (4 Outback FX3048), the battery bank (24 2-Volt Surrette-Rolls 2KS 33PS), and the DC and AC conduit boxes containing circuit breakers, transformers, and the lightning arrestor. The DC electricity generated by the solar panels charges the battery bank through the charge controllers. The DC electricity from the batteries (i.e., 48V DC) is converted to AC electricity (i.e., 120 V or 240 V of AC) through the inverters and is available for use in the house. Figure 38 shows this arrangement in a simple schematic. The battery arrangement was designed to prolong the life of the batteries. The 24 2 Volt batteries were connected in series, making the charging process uniform through the batteries and minimizing the impedance problem that occurs in parallel arrangements of 3 or more strings of batteries. At the time of sizing a battery bank, it is recommended to provide storage for a period of three to four days without sunlight. It is not recommended to discharge the batteries more than 50% of their total charge since they will require more time to get fully charged and the battery life can be diminished. In the TAMU house the system was designed to endure 5 days without sunlight to be prepared for the possible scenario of no sunlight for the full week of competition. Several teams at the SD used 12V batteries using up to four strings of batteries in parallel connection; although this arrangement works conveniently for a short period of time. Having multiple strings can lead to uneven charge. All electricity loads in the house were carefully balanced with the inverters to avoid overloading the systems with too much electricity power draw. A one line drawing of the PV system is shown in Figure 39, and Figure 40 presents the components and locations of the system within the house.

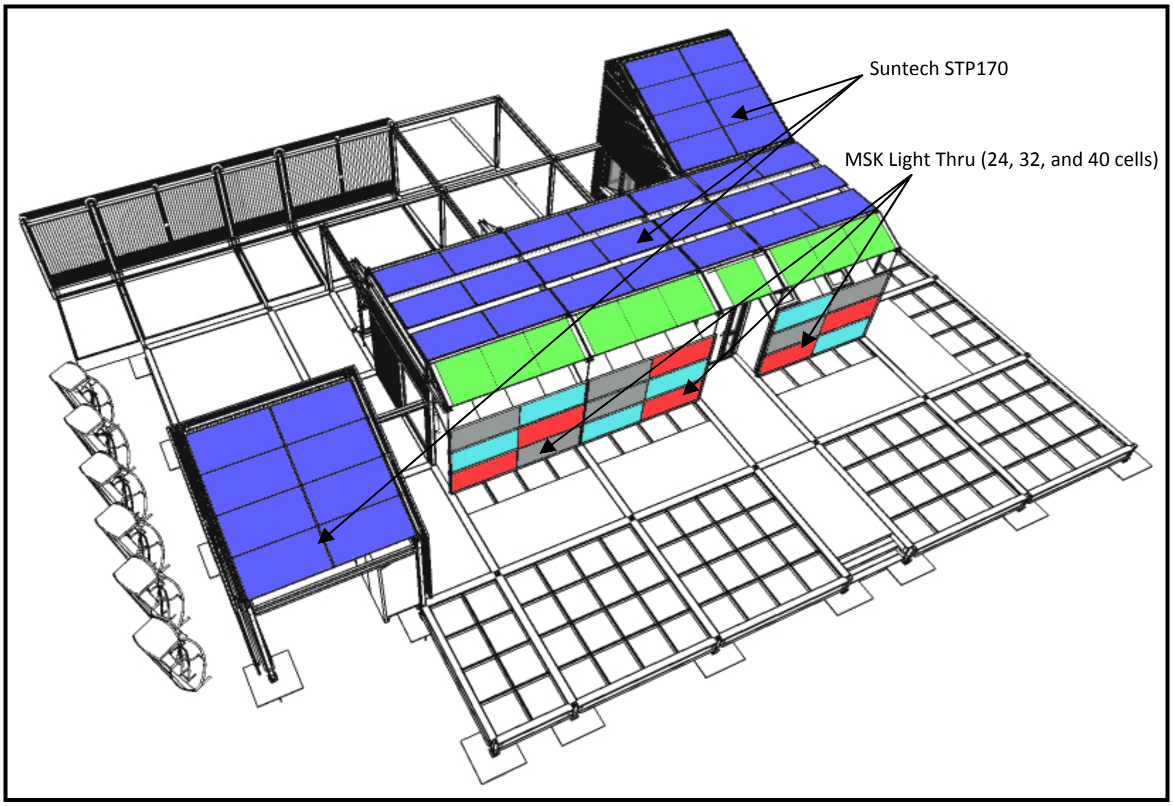


Figure 37: PV panels layout.

Table 10: Specifications for PV panels used at the TAMU house.

Specifications	High Efficiency PV	BIPV		
	Suntech STP 170	MSK Light Thru (24 Cells)	MSK Light Thru (32 Cells)	MSK Light Thru (40 Cells)
Module Dimensions	1580x808 (mm)	1476x716 (mm)	1476x716 (mm)	1476x716 (mm)
Number installed	37	6	6	6
Module Short Circuit Current at Reference Conditions (Isc)	5.14 (Amp.)	5 (Amp.)	5 (Amp.)	5 (Amp.)
Module Open Circuit Voltage at Reference Conditions (Voc)	43.8 (Volt.)	14.6 (Volt.)	19.5 (Volt.)	24.4 (Volt.)
Reference Temperature	25 C	25 C	26 C	27 C
Reference Insolation	1000 (W/m^2)	1000 (W/m^2)	1000 (W/m^2)	1000 (W/m^2)
Module Voltage at Max Power point and Reference Conditions (Vmp)	35.2 (Volt.)	12.4 (Volt.)	16.5 (Volt.)	20.6 (Volt.)
Module Current at Max Power point and Reference Conditions (imp)	4.83 (Amp.)	4.7 (Amp.)	4.7 (Amp.)	4.7 (Amp.)

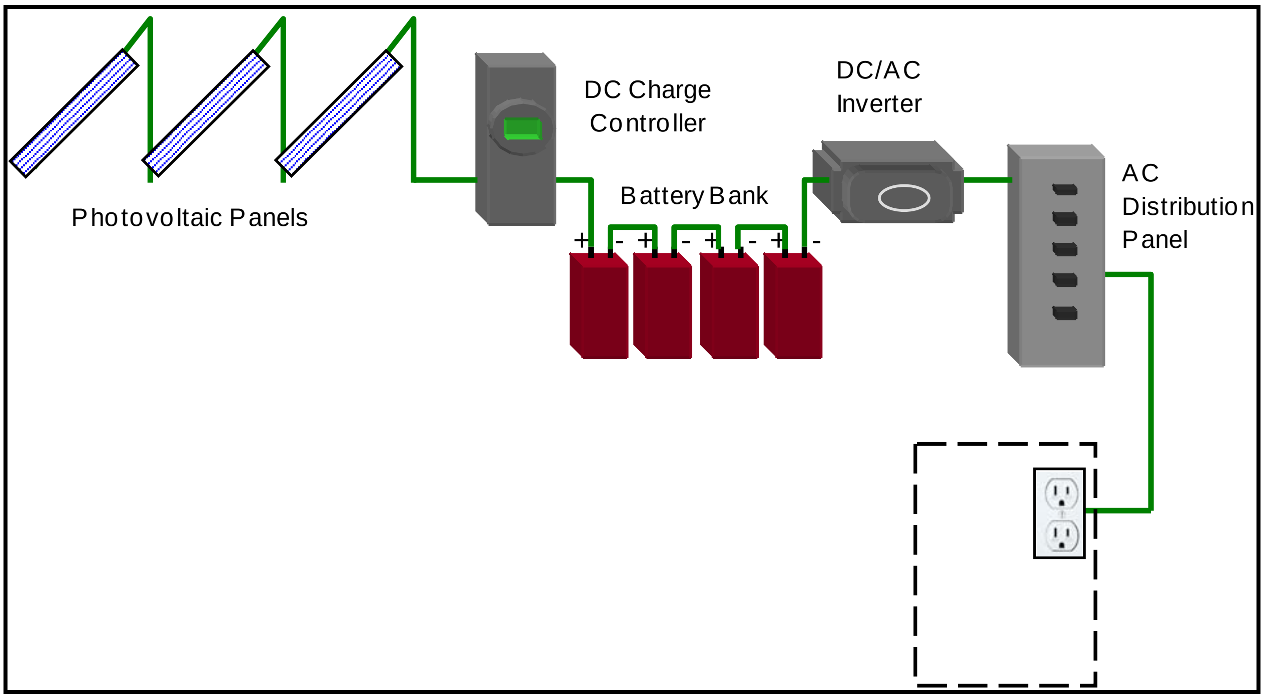


Figure 38: Simple schematic of the PV system.

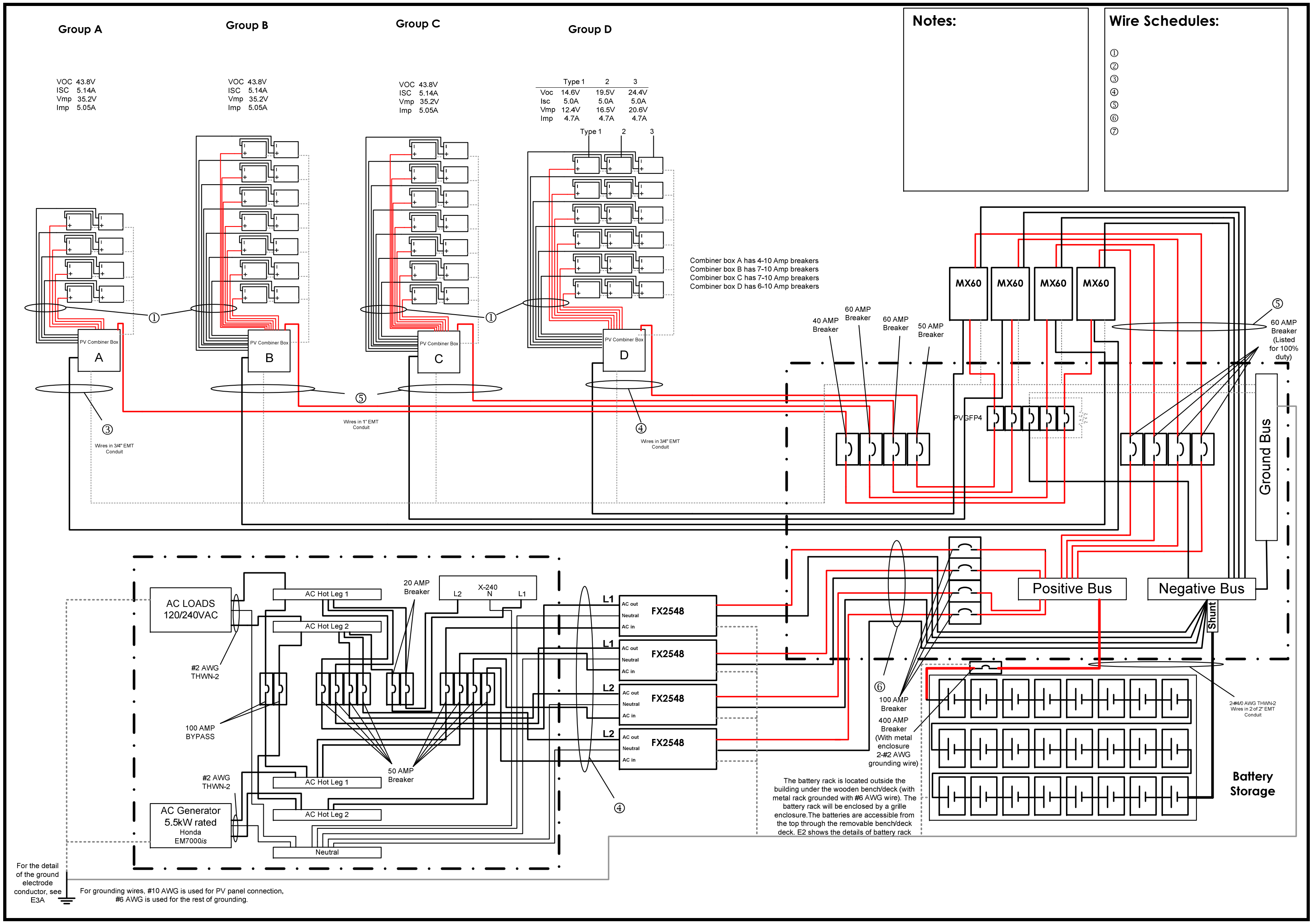


Figure 39: One-line drawing of PV system.

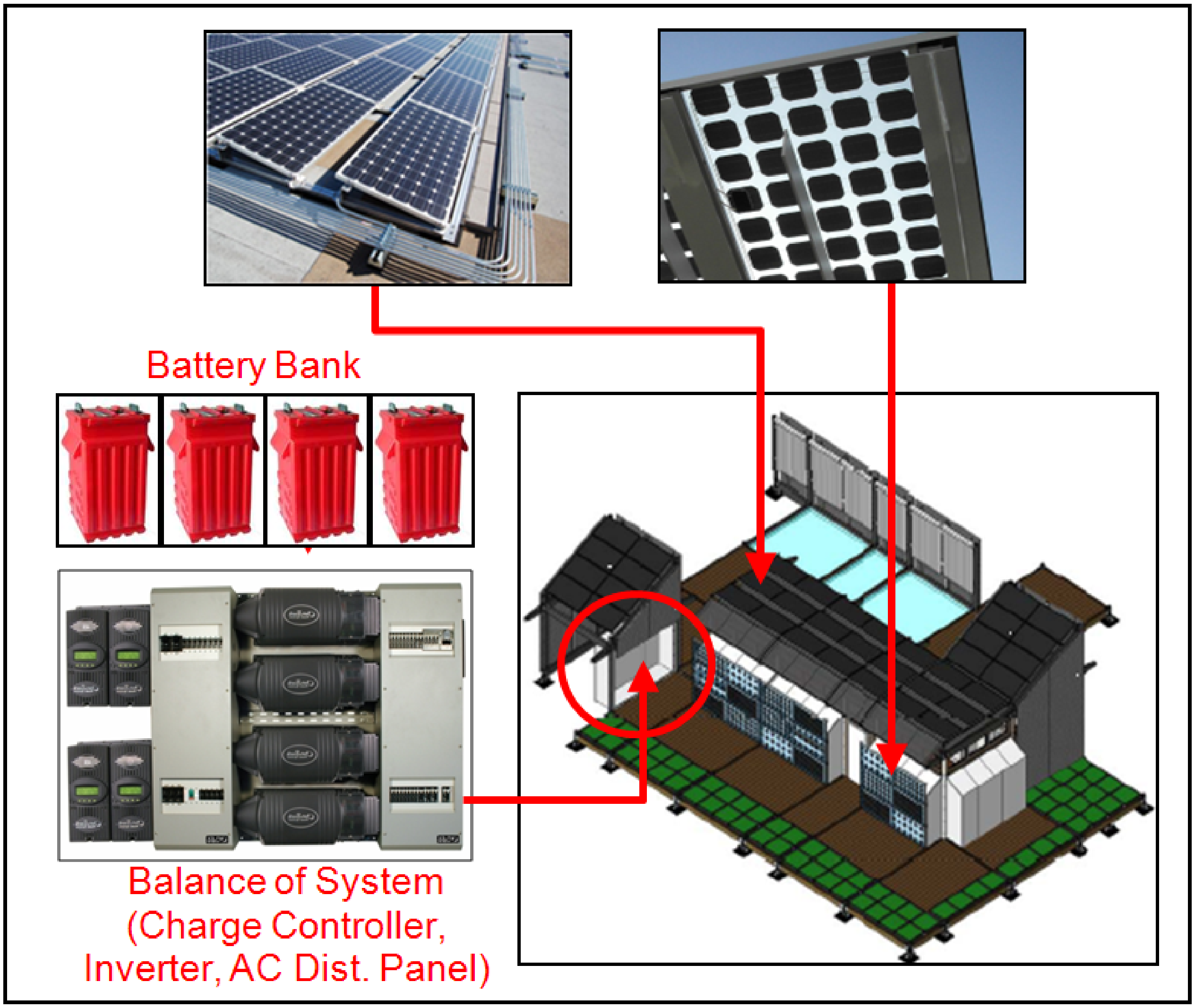


Figure 40: Components and locations of the PV system in the house.

Section 3.3.4.5. AC Electrical System Description

The AC electrical system was design to accommodate the modularity of the gro-Home concept. To accomplish this, every gro-Wall had its own electrical subpanel sized accordingly to the loads in each gro-Wall. The subpanels had disconnects which were connected to a main disconnect located at the west side of the core of the house. Having these disconnects made the reassembly processes easier and faster. Another main disconnect was located at the in the garage module of the house were the AC main panel was located. Figure 41 and Figure 42 show an example of the plugs used for the gro-Walls and the main connection points at the garage module respectively. In Figure 43, the schematic layout of the AC electrical system is presented. All wires, conduits, and breakers were sized according to the NEC code standards. Following the NEC code on accessibility issues was extremely challenging due to the modularity concept where every subpanel needed to be inside the gro-Walls which already had their cabinets, appliances, and necessary equipment. Drawings that show the receptacle and lighting plans are shown at the appendix.

Figure 41: Plug used for gro-Wall electric connections.

Figure 42: Garage module main connection point for electrical plugs.

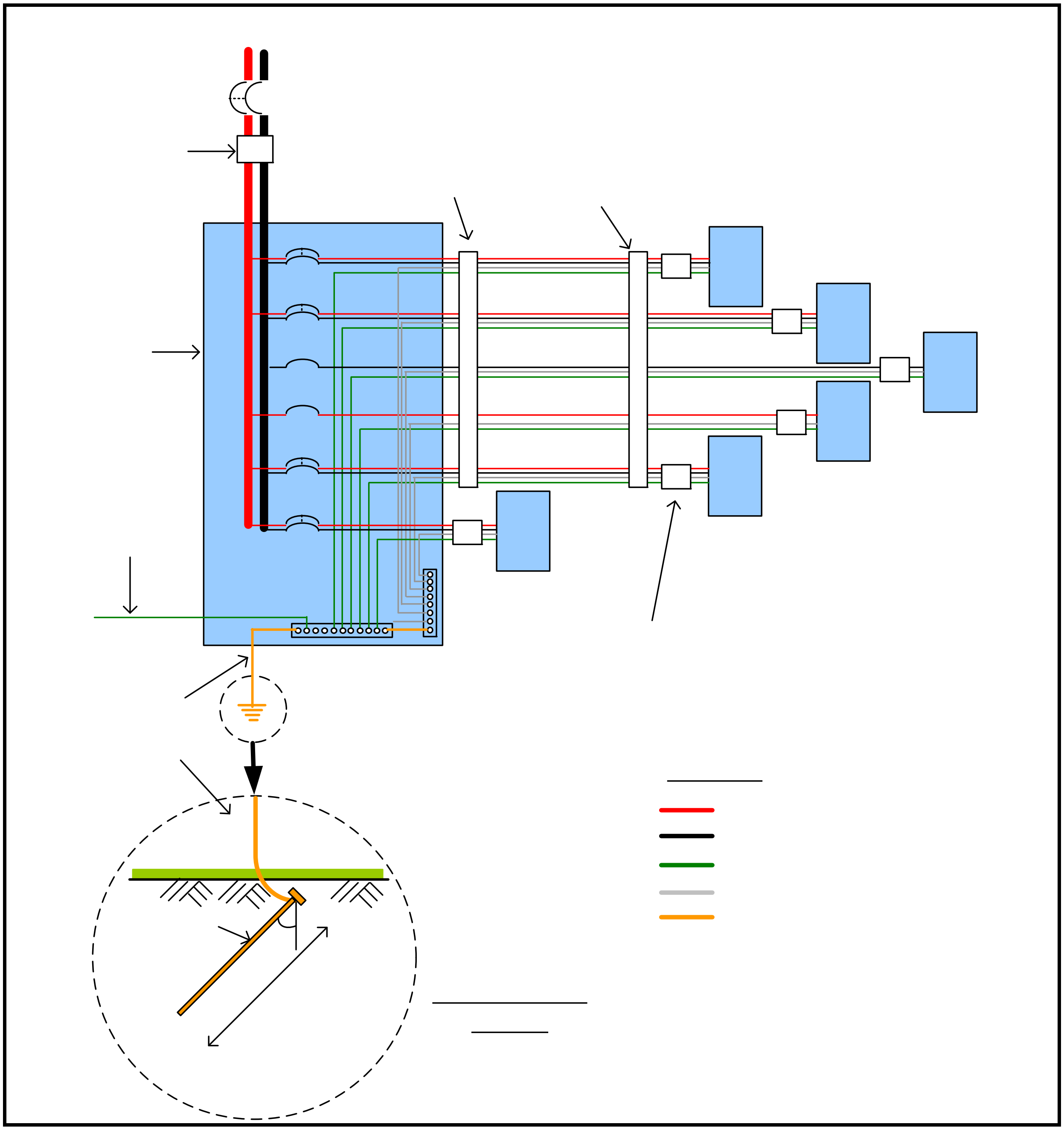


Figure 43: AC electrical system schematic layout

Chapter 4: Construction

This chapter includes the details of the construction process of the TAMU solar house, which consisted of the local construction at Bryan/ College Station, the transportation of the house to the National Mall, and the construction process at the National Mall. The transportation of the house is presented since it was an additional challenge to design a house with transportation capabilities similar to a mobile home.

Section 4.1. Construction at Bryan/College Station

The construction of the house officially started in the summer of 2007. Previous to this date experimental prototypes were constructed for the square modules of the house (i.e., studio and garage modules). Similarly, some aspects of the gro-Walls were started before the summer. It is important to clarify that some tasks of this construction process never stopped until the house was finished at Washington, D.C. a few hours before it opened. Welding, soldering, wiring, and other installations were some of the activities that lasted throughout the whole construction process. Another time consuming task that occurred during this construction phase was the ordering of parts and components. Special orders were made for custom-made equipment and components such as: plastic bladder tanks, stainless steel tanks, ducts, windows, counter tops, the bathroom gro-Wall, and the Light Thru PV panels. The standard equipment and components ordered consisted of: the heat pump, a dehumidifier, high efficiency PV panels, solar thermal collectors, other pumps, valves, controllers, lighting fixtures, batteries, an ERV, piping, tubing, fittings, appliances, wires, breakers, relays, electrical boxes, receptacles, BOS, curtains, a TV, furniture, and water heaters. In addition, there were other sets of components and equipment that were assembled or made by students, including: doors, cabinets, bed, steel structure of the decking and gro-Walls, building foundations, deck floor, stairs, hand rails, ADA ramp, and light-wing. In Figure 44 to Figure 50 multiple images of the construction at Bryan/College Station are shown.

It is recommended to finish the construction phase before sending the house to its final destination at least one month in advance. This time would be significant for testing of the mechanical and electrical systems with a special focus on balancing and operation of the system controls. Unfortunately, the TAMU team was not able to accomplish this before transporting the house to Washington, DC. One of the reasons for this was that almost every simple component of the house was designed, installed or constructed by the students and not professionals.

Figure 44: First attempt to attach a gro-Wall to a core unit.

Figure 45: TAMU student using a computer-controlled laser cutter during the manufacturing process.

Figure 46: Assembly of the photovoltaic BOS and solar thermal systems (photo by John Peters).

Figure 47: Manually fabricated heat exchanger for potable water inside solar thermal tank (photo by John Peters).

Figure 48: Installation of a window and door frame to the main core of the house (photo by John Peters).

Figure 49: Installation of ERV inside the HVAC gro-Wall (photo by John Peters).

Figure 50: Production line for the deck modules (photo by John Peters).

Section 4.2. Transportation to the National Mall

The transportation of the house to Washington occurred in only a few days. The steel frame of the core module was welded by professionals in order to keep it intact during the process. Axles and wheels were attached to the core and it was pulled by a truck rated for heavy load. All windows and open sections of the core were covered with plywood to prevent any projectiles from hitting the windows during the transportation. Figure 51 and Figure 52 show the moment when the core left the Bryan/College Station facility. The gro-Walls and deck modules were transported on a flat bed. All tools, equipment, and appliances were shipped in two separate semi trailers. The following section will explain the arrival to the National Mall and the construction process in that place.

Figure 51: Truck pulling the TAMU house (photo by John Peters).

Figure 52: TAMU house leaving Bryan/College Station facility (photo by John Peters).

Section 4.3. Construction at the National Mall

During the reassembly process at the National Mall each team has approximately 9 days to reassemble, test, and make final changes to their houses. During this process, teams need to schedule group meetings, meetings with the organizers, time for instrumentation installations, and site inspections in addition to their work in the house. Group meetings are usually scheduled on a day-to-day basis to program the goals for each day. The daily meetings with the organizers are usually informational, and tend focus on safety and future activities during the competition. The DOE had safety officials checking the houses at all times to ensure that all construction activities were performed safely. The organizers also provided qualified instrumentation officials that were in charge of installing sensors for the monitoring of the houses. They installed light sensors, temperature and relative humidity sensors, DC power monitoring (i.e., DC current sensor (shunt), and a DC voltage divider), and data logger. A timeline of key events during the construction process at the National Mall is presented in the following pages of the report. The daily blog documentation from the TAMU SD website is shown on the Appendix.

October 2

Figure 53: View of the National Mall before the construction of the houses.

Figure 54: Informational banners for the attending public at the National Mall.

Figure 55: Reviewing the construction schedule in a team meeting (photo by John Peters).

October 3

Figure 56: TAMU main core arrives to the National Mall. The white plastic sheet had to be placed in front of the tires to prevent damage to the National Mall grass (photo by John Peters).

Figure 57: Lifting the main core for wheels removal (photo by John Peters).

Figure 58: Foundations and main core set at National Mall (photo by John Peters).

Figure 59: Installation of the first gro-Wall using a fork lift (photo by John Peters).

Figure 60: Installation of the first gro-Wall after solving tolerance issues (photo by John Peters).

Figure 61: Installation of three gro-Walls (photo by John Peters).

October 4

Figure 62: View of the National Mall after first day of on-site construction.

Figure 63: Installation of the garage gro-Wall (photo by John Peters).

Figure 64: All gro-Walls installed (photo by John Peters).

Figure 65: Moving high efficiency PV panels to the roof using forklift (photo by John Peters).

Figure 66: High efficiency PV panels installation (photo by John Peters).

Figure 67: Pre-assembly of pipe clamps (photo by John Peters).

October 5

Figure 68: All high efficiency PV panels mounted on the roof (photo by John Peters).

Figure 69: HVAC system duct installation (photo by John Peters).

Figure 70: Arranging batteries before wiring process (photo by John Peters).

Figure 71: Finalization of soldering of pipes inside Garage gro-Wall (photo by John Peters).

October 6-7

Figure 72: Installation of architectural rain screens. Note safety hardness required for safety (photo by John Peters).

Figure 73: Soldering of hot water loops under Garage gro-Wall (photo by John Peters).

Figure 74: Insulation of hot water lines (photo by John Peters).

Figure 75: Installation of PEX lines and insulation (photo by John Peters).

Figure 76: Installed light wings and doors; moving appliances inside the house (photo by John Peters).

Figure 77: Soldering steam relief valves for solar thermal loop (photo by John Peters).

Figure 78: Attaching copper lines to solar thermal manifolds (photo by John Peters).

Figure 79: Finalized installation of solar thermal manifolds (photo by John Peters).

Figure 80: Insulation of pipes and electrical wiring (photo by John Peters).

Figure 81: Deck installation finalized (photo by John Peters).

October 8

Figure 82: Porch screens and rain screens installed (photo by John Peters).

Figure 83: Solar thermal tank insulation installed (photo by John Peters).

Figure 84: Welding the accessibility ramp (photo by John Peters).

October 9-10

Figure 85: Receiving water from water truck (photo by John Peters).

Figure 86: Filling water troughs for fish ponds. Note evacuated tubes already installed (photo by John Peters).

Figure 87: Filling solar thermal tank (photo by John Peters).

Figure 88: Garden and accessibility ramp almost finalized. Installation of Light Thru PV panels frames (photo by John Peters).

Figure 89: Installation of Light Thru PV panels (photo by John Peters).

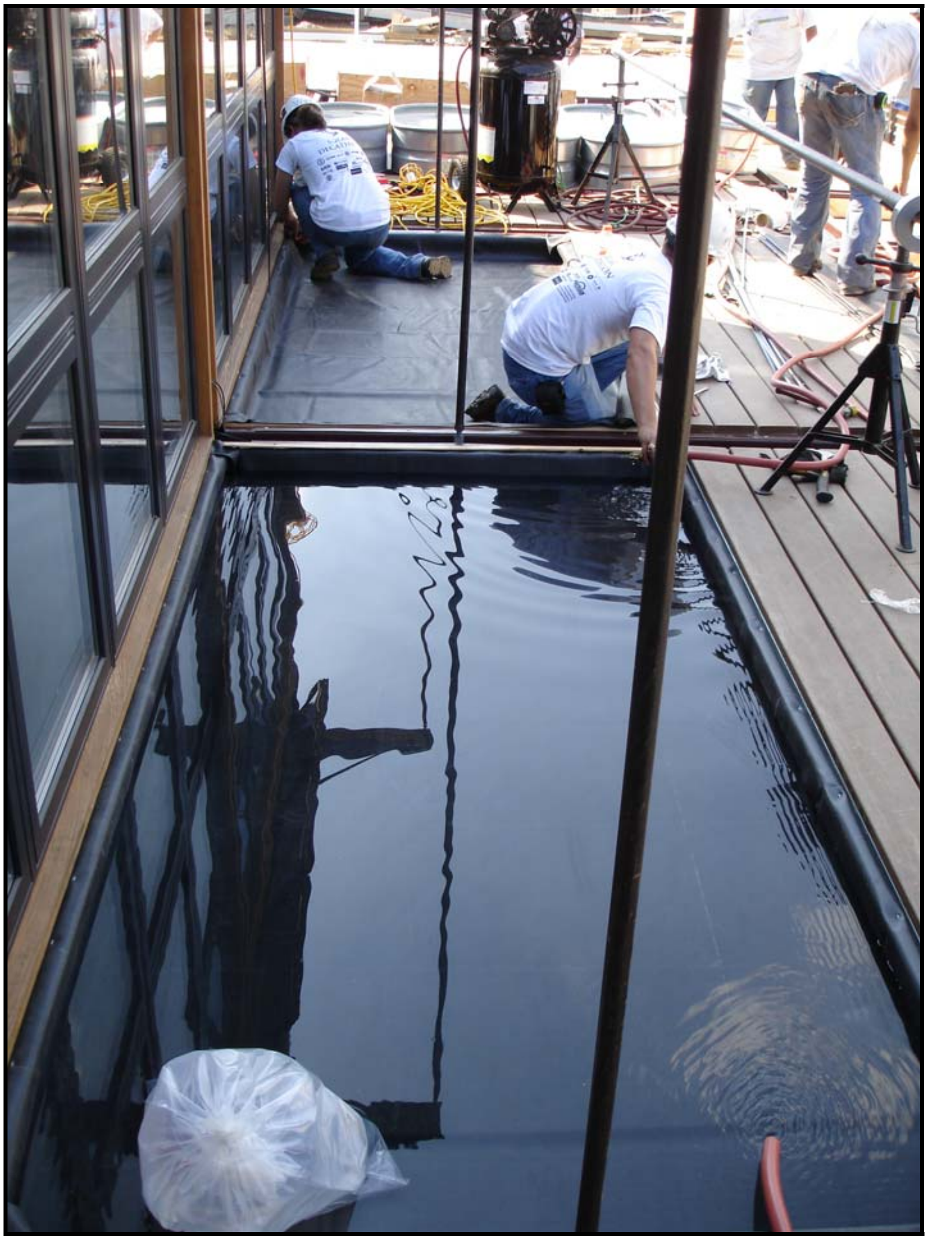


Figure 90: Installation of pond liners and transference of water from water troughs to actual ponds (photo by John Peters).

Figure 91: Filled ponds and covered evacuated tube collectors (photo by John Peters).

Figure 92: Main supply tank full of water (photo by John Peters).

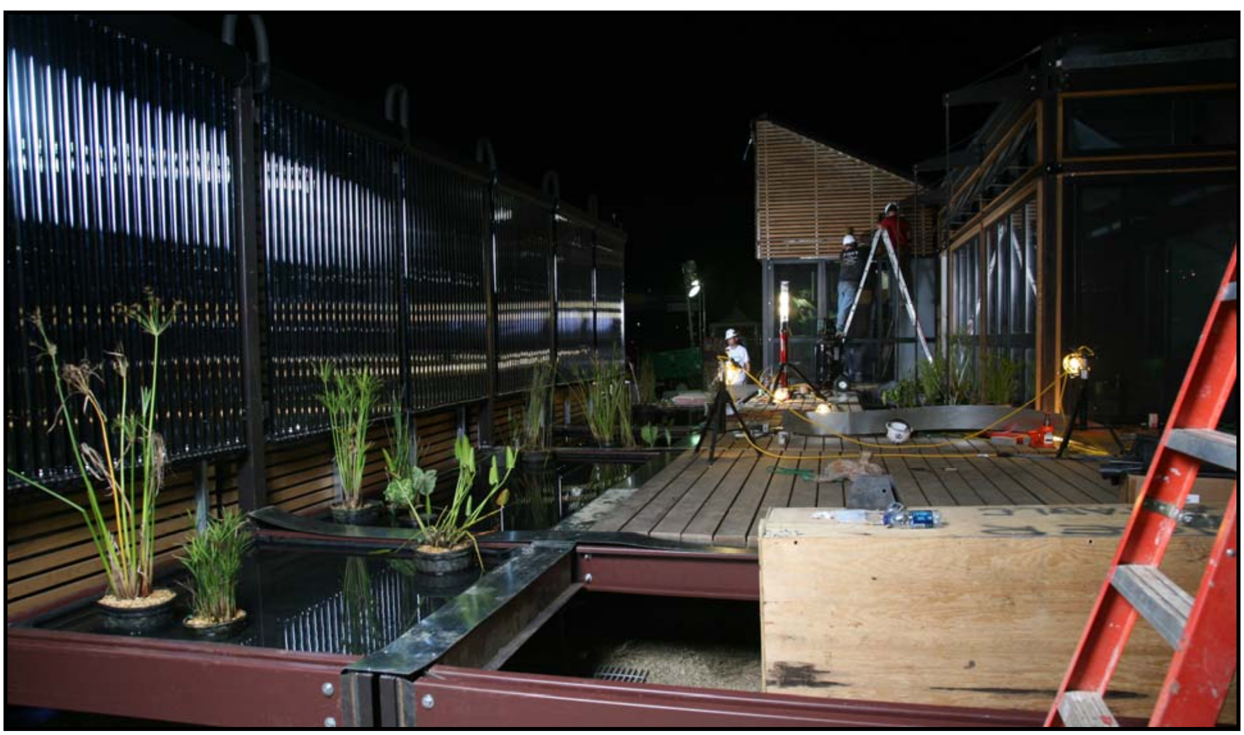


Figure 93: Uncovered solar thermal panels and protected battery bank (photo by John Peters).

Figure 94: TAMU team taking a late night break (photo by John Peters).

Figure 95: NREL instrumentation personnel having a cold drink offered to them by TAMU students (photo by John Peters).

Figure 96: Installation of the photovoltaic BOS controller (photo by John Peters).

Figure 97: Fully-wired battery bank (photo by John Peters).

Figure 98: Live plants at the TAMU gro-Home garden (photo by John Peters).

Figure 99: TAMU team members being interviewed (photo by John Peters).

Figure 100: Final touches to the air duct (photo by John Peters).

Figure 101: Frustration figuring out the HVAC control system problems (photo by John Peters).

Figure 102: Using soapy water to check leaks in the inflated main supply tank (photo by John Peters).

Figure 103: Installation of front stairs (photo by John Peters).

Figure 104: Hand rail installation (photo by John Peters).

Figure 105: House fully furnished (photo by John Peters).

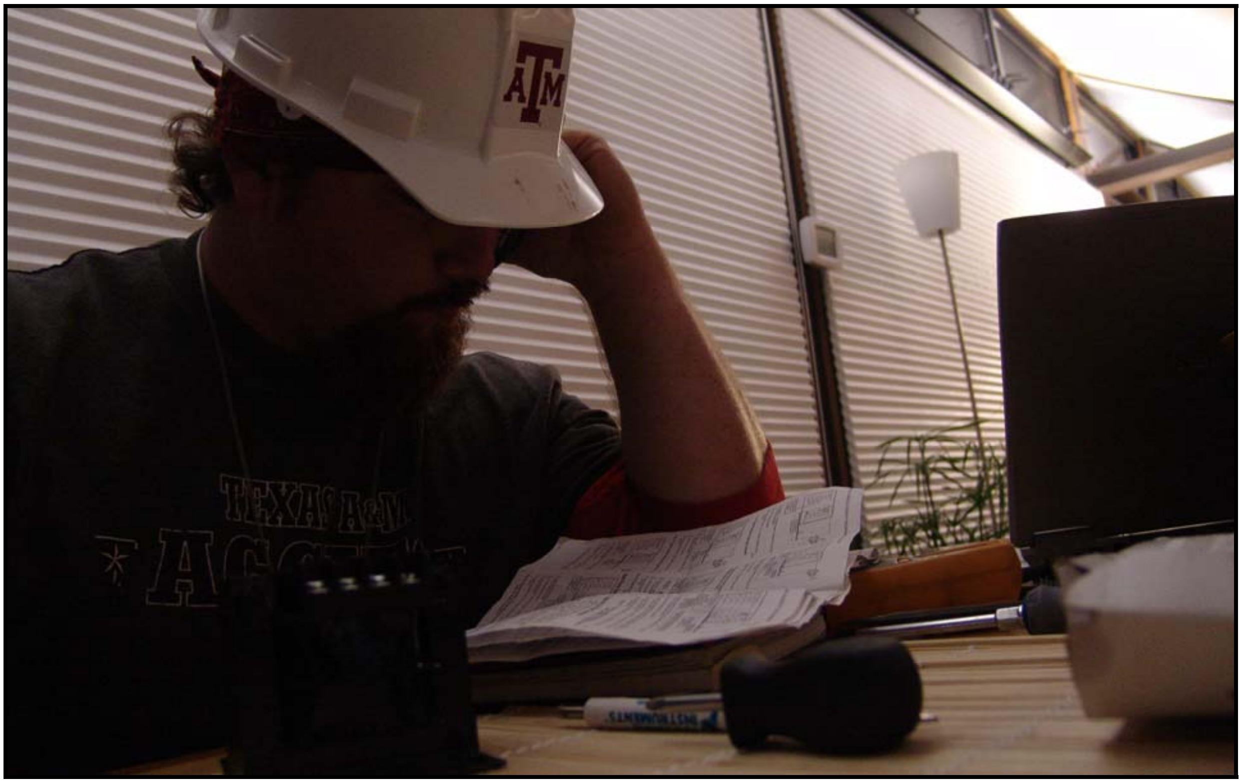


Figure 106: Late night effort to figure out problems with the HVAC control system (photo by John Peters).

Figure 107: Fixing broken pressure switch in main supply pump (photo by John Peters).

Figure 108: Cutting pieces of a plastic bladder tank in order to patch the main supply tank using a heat gun (photo by John Peters).

Figure 109: Final cleanup before the start of the competition (photo by John Peters).

October 11

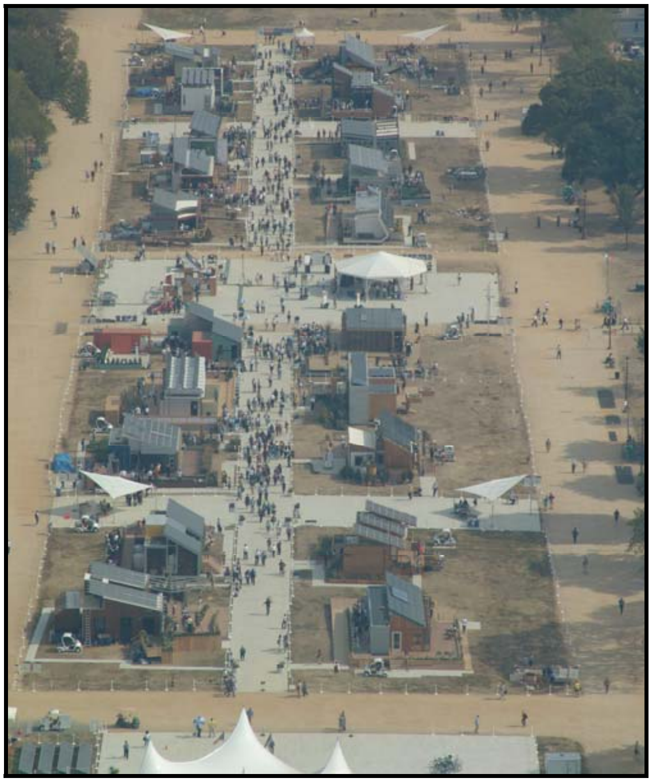


Figure 110: View of the solar village when it opened to the public.

Figure 111: Last minute fix of deck modules connections in order to comply with the ADA accessibility regulations (photo by John Peters).

Figure 112: Recycled steel pieces glued to the leather floor recycled from BMW cover seats (photo by John Peters).

Figure 113: TAMU solar house after the construction was completed at the National Mall (photo by John Peters).

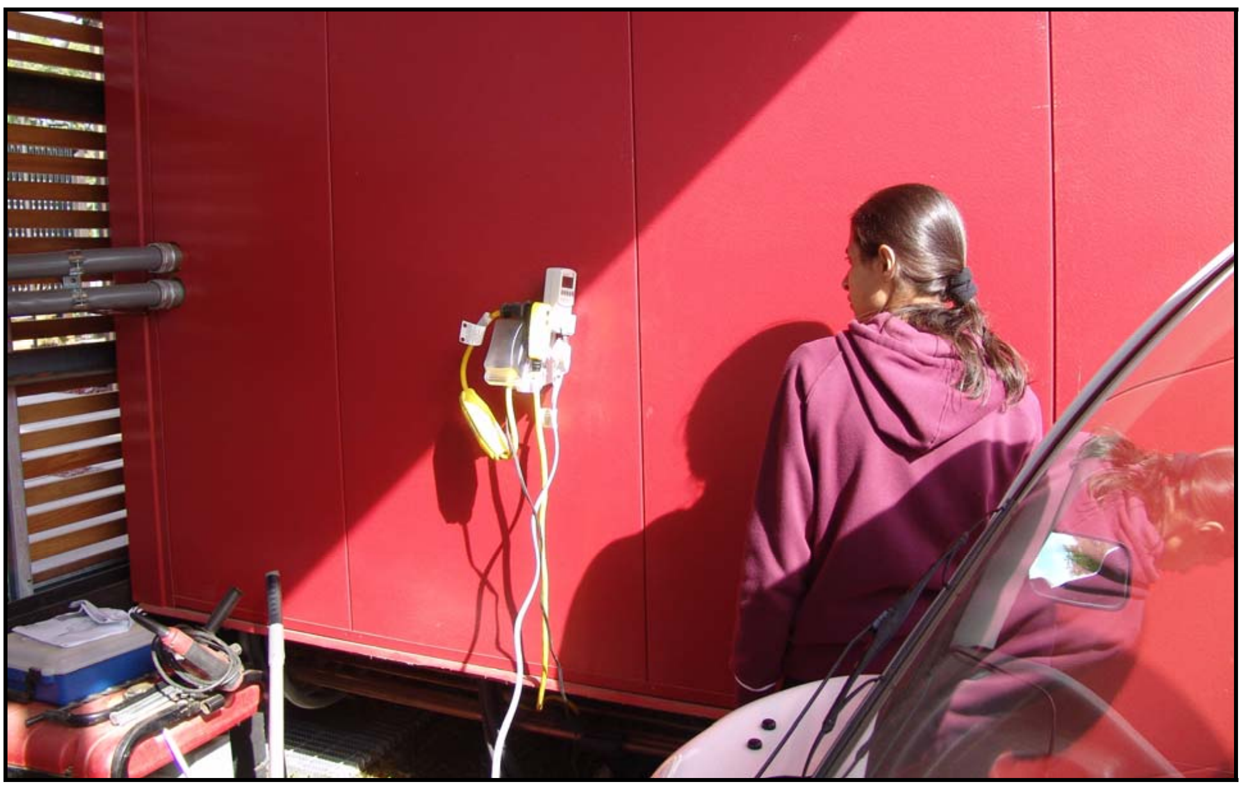


Figure 114: Testing the electric car charger power meter (photo by John Peters).

Figure 115: Proving to the Washington, DC Police that the electric car was part of the competition (photo by John Peters).

Figure 116: Checking the tire pressure of the car in order to minimize friction (photo by John Peters).

Chapter 5: Operation

Section 5.1. Tasks, Contests, and Strategy

Each one of the ten contests in the Solar Decathlon (SD) competition requires the completion of specific tasks for the assignment of points. In order to receive partial or full points in each contest, teams applied different strategies. This section presents the strategy used by the TAMU SD team with the intention of completing specific tasks within each contest. The final outcomes and recommendations will be discussed in the following chapter.

Architecture

The task that needed to be completed with the Architecture contest included the preparation of drawings and an in-depth presentation and explanation of the design concept and the use of space. To accomplish these drawings were prepared throughout the two-year design and implementation process. At the time of preparing the house for the contest week, specifically the Architecture contest, there were a few of things that could have been done. The points for this contest were assigned by a panel of judges. Students showcased the house with a tour of the facilities and a thorough explanation of how the TAMU house tried to incorporate a new building system integrating a sustainable design with the life cycle process of a residential building. The main strategy for this contest was to express honesty to the judges and to focus on the innovation and message that the house was presenting with a very deep focus on the plug-and-play adaptable modular systems.

Engineering

The Engineering contest consisted of submitting a series of three energy simulation analysis reports and the subjective design evaluation. This contest did not consider how well the systems worked during the contest week. Instead, the engineering design was evaluated as a whole considering the building envelope, indoor environmental control, mechanical, electrical, and plumbing systems according to their functionality, efficiency, innovation, robustness, and short- and/or long-term economic value. The TAMU SD team also needed to walk the judges through a house tour explaining the multiple assets of the design. The strategy of the TAMU team for this contest was to focus on the amount of work done by students and not professionals within the systems design. The aspect of designing the Mechanical, Electrical, and Plumbing (MEP) systems according to the modular building structure was also a main focal point. As part of the strategy, the team tried to use as much energy as possible coming from the solar thermal panels since this solar energy collection system contains the highest efficiency in comparison with the PV panels. Prior to the judges' tour, once the names of the judges were known, the team studied the background of each judge in order to focus on areas related to their work.

Market Viability

The Market Viability contest along with the Architecture and Engineering contest was one of three events that were worth more than 100 points. This contest consisted of four main parts: an economic analysis report, a house tour meant to exalt economic effectiveness and the market appeal of the house, the project deliverables throughout the two years of competition, and the code and regulation compliance of the house. For the economic analysis report a jury of experts evaluated the economic effectiveness of the building-integrated photovoltaic design, and the team's ability to effectively utilize economic optimization and evaluation techniques to inform design decisions. The jury also evaluated the team's cost estimate of a marketable version of its competition house following criteria such as: cost estimating abilities, assumptions used for the analysis, simplifications, and economic performance. For the house tour, a different jury comprised of homebuilders evaluated the responsiveness of the team's project to the demands of a defined target market. The criteria used relied on the livability, buildability, and flexibility of the house. The third part was evaluated by the organizers and consisted of the timeliness, completeness, detail, accuracy, and overall quality, of a series of project deliverables submitted prior to the week-long competition at the National Mall. Finally, the fourth part consisted of complying with the codes and regulations that applied for the competition such as: safety practices, ADA, and building codes among others. The TAMU strategy for this contest was to emphasize the easy to use flexible building idea. The team submitted all the required submittals and had an on-site safety official in order to maintain a safe environment at all times during the construction. In addition, all team members participated of a ten hour Occupational Safety and

Health Administration (OSHA) training. Unfortunately, the tour by the judges was very brief and the team had only a few minutes to review each point.

Communications

The Communications contest was evaluated in two areas: the design and update of a team Website, and the tours provided to visitors at the National Mall. All team's websites needed to follow specific rules and requirements from the organizers. Tours were given to VIPs before the start of the contest week and to visitors during the contest week. Each team needed to showcase their homes to the visitors for five to six hours every day with the exception of one day when the houses were closed to the public. The score obtained in the tours section of the contest depends heavily on how team members project themselves and how valuable the information that was provided during the tours. A good personality is considered a critical asset for team members giving tours. The TAMU team divided the tour in five different stations in order to keep a continuous flow of people at all times during the tours. In addition, posters and additional information were available with the intention of giving flexibility to the public. Some teams may overlook the Communications contest since it requires neither engineering nor architectural design; however it requires work and innovation to score well. Unfortunately, the strategy of the TAMU team for this contest was not clearly established. The team provided good information during the tours, but it was deficient in information about innovation. For the website, daily blogs and pictures were posted daily during the competition.

Comfort Zone

The Comfort Zone contest consisted of maintaining recommended interior temperature and relative humidity levels at almost all times during the contest week. Teams did not need to maintain those conditions during tours. After the tour hours, teams had one hour to condition the space to the required values. The strategy for this contest consisted of three main ideas. The first was to check that the readings obtained by the thermostat and humidistat of the system were the same readings that the organizer's sensors were obtaining due to their dissimilar locations inside the house. The second was to try to keep all student members outside the house in order to allow the HVAC system to overcome the house loads alone. This was also intended to minimize latent loads generated by human bodies. The third and last strategy was a forced action that came with the unfinished control system problem. The idea was to monitor the weather data and the solar thermal storage temperature to be in a relatively fair position to predict the mode of operation needed for the night period since the controls were manually operated and could not be changed wirelessly or via the web.

Appliances

The Appliances contest was the most task-oriented contest of the whole competition. During this contest, teams needed to control the temperature inside the refrigerator and freezer, use the clothes washer and dryer, use the dishwasher, cook, vaporize water, and use a computer during certain hours of the day. To qualify for this contest each team needed to maintain temperature levels between 34 and 40 degrees Fahrenheit in the refrigerator and between -20 and 5 degrees Fahrenheit in the freezer. For this part of the contest, the TAMU team focused on having several water bottles inside each unit. This helped to maintain uniform interior temperatures. The TAMU team also was careful not to open or close the doors unless absolutely necessary.

For clothes washing, each team needed to wash 12 big towels provided by the organizers. Along with the towels, a temperature sensor was placed in the clothes washer to assure that the water used for the cycle reached 110 °F. This was necessary to obtain full points for the task. The main technique the TAMU team used to save water and energy during this contest was to place all twelve towels together in the same load (Figure 117). Although this was not the usual way of using a clothes washer it was completely legal since the rules required to wash the (clean) towels in a normal mode. It did not specify that the towels needed to be cleaned. The water going into the washer was pre-heated by the solar thermal system with the intention of minimizing the use of the electric element inside the washer. The clothes drying consisted of completely drying the previously washed towels. For this task, the towels were weighed before going inside the clothes washer. After the clothes drying, the towels needed to weigh the same or less than they weighed before.

Another task consisted of using the dishwasher using the normal setting. In a similar fashion as the clothes washer task, a temperature sensor was placed inside the dishwasher that needed to achieve 120 °F at some point during the cycle (Figure 118). The water going into the dishwasher was also preheated using the solar thermal system. The cooking task consisted of vaporizing five pounds of water in less than two hours using a kitchen appliance. For this task the TAMU team evaluated the energy consumption of several different types of cooking appliances. Unfortunately, the most efficient appliance did not comply with the Solar Decathlon rules and regulations, leaving the team with the second best option. This was the kitchen cook-top with a large commercial-grade aluminum pot that held 5 lbs. of water. In order to prevent the 5 lbs. of water vapor from entering the kitchen air, which would then require removal by the air-conditioning system, a special lid was chosen for the pot that had a large spoon notch. This lid directed the water vapor toward the kitchen exhaust fan located directly behind the cook-top. Finally, the team needed to use a computer during different times of the day. There was no specific strategy for the computer usage.

Figure 117: TAMU team member inserting towels into the clothes washer (photo by John Peters).

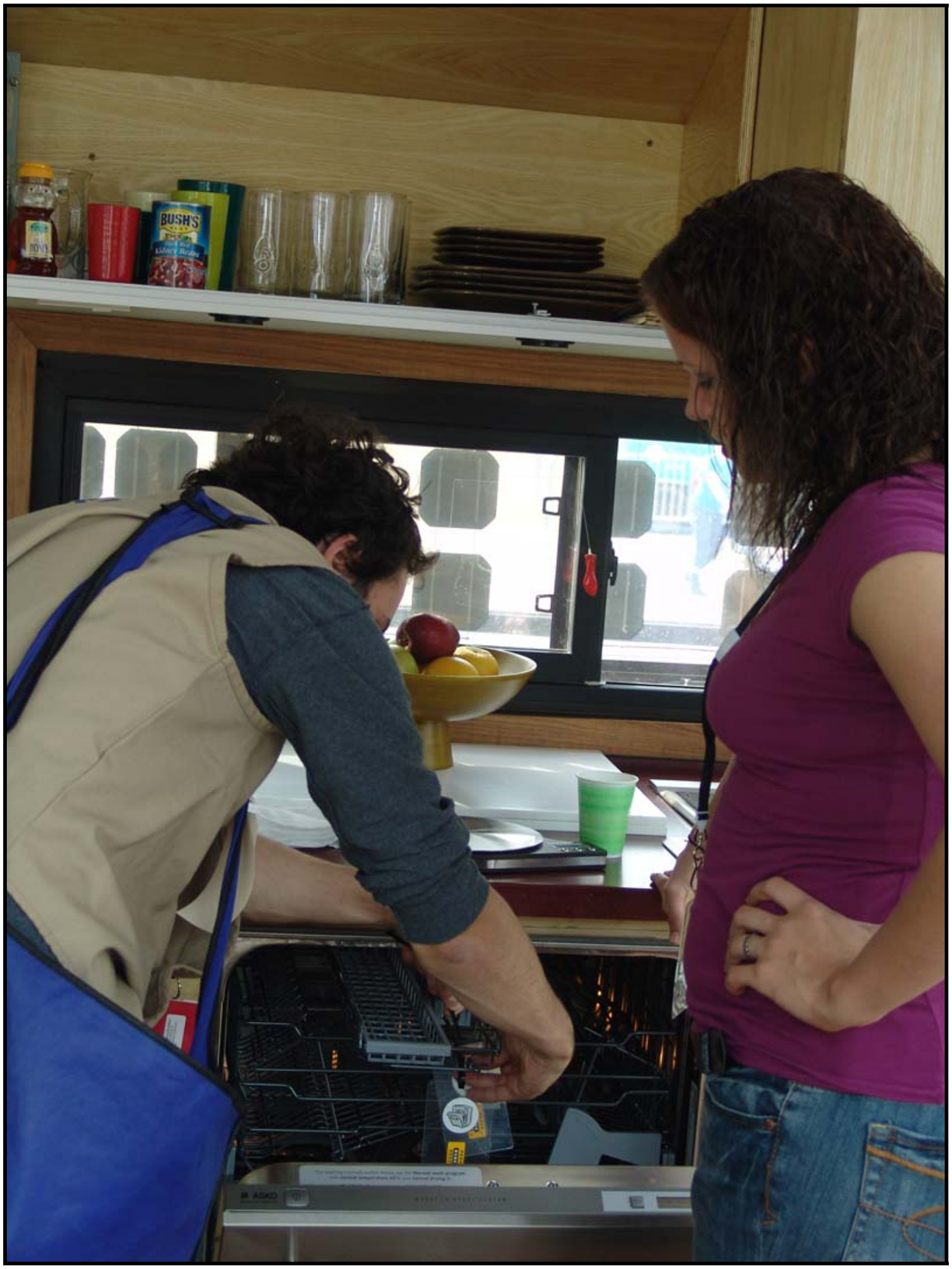


Figure 118: Solar Decathlon Official Observer installing a temperature sensor inside the TAMU dishwasher (photo by John Peters).

Hot Water

For this contest, each team had to deliver at least 15 gallons of hot water in no more than 10 minutes to qualify for points. The maximum points were earned by delivering an average temperature of at least 110 °F. The TAMU team planned carefully for this contest during the design process. In order to cut the electricity consumption of the main pressurization pump, a 36 gallon pressurized tank was chosen. This allowed the team to provide one full shower test without starting the main pump. Due to the long distance between the water heaters and the shower, it was also necessary to remove the cold water from the hot water lines one minute before each shower test. Figure 119 shows the cold water removal process before a shower test. Figure 120 shows a staff member installing the necessary fittings and sensors to complete a shower test.

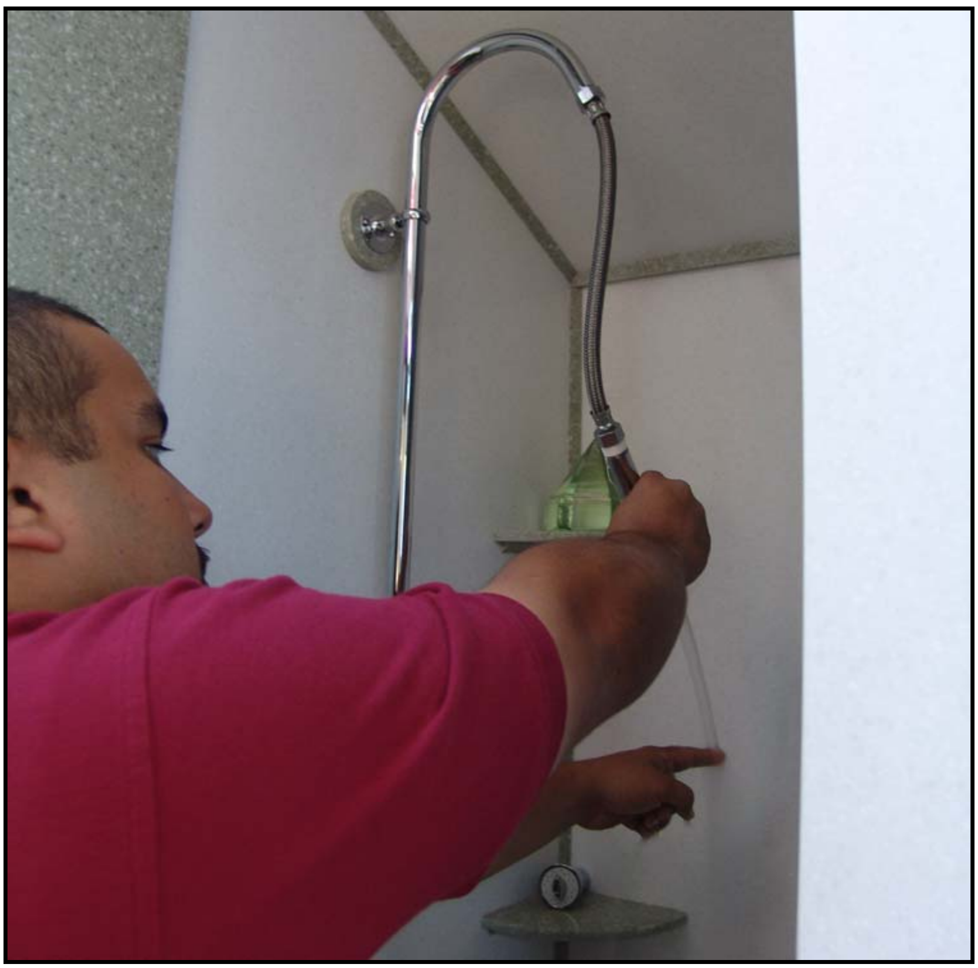


Figure 119: TAMU team member removing cold water from the hot water pipeline for the shower test (photo by John Peters).

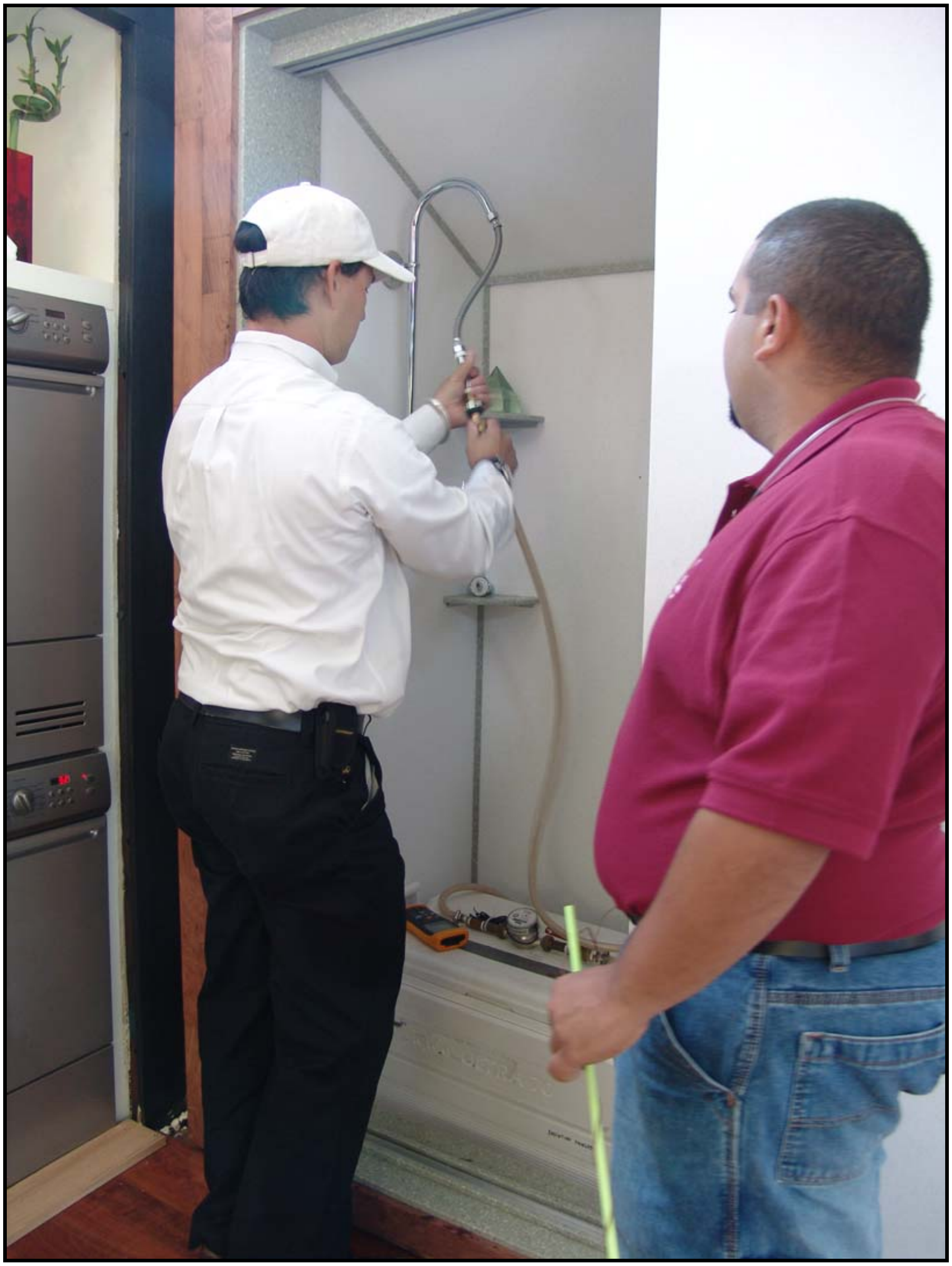


Figure 120: Official instrumentation staff preparing the setup for a shower test (photo by John Peters).

Lighting

The Lighting contest was evaluated in four different areas: lighting quality of the electric fixtures, daylighting quality, nighttime house lighting, and daytime workstation lighting. In the electric lighting quality contest, a jury of lighting experts evaluated the design and implementation of the house's interior and exterior electric lighting systems. The jury assigned points for:

- Identifying and responding to the specific client's lighting requirements,
- Designing rich and varied lighted spaces that have adequate lighting for tasks and good color rendition,
- Selecting attractive luminaries that properly distribute light,
- Installing lighting controls that enhance the ease of operation, flexibility, and energy efficiency of the lighting system, and
- Designing exterior lighting systems that provide safety, security, and aesthetics for residents, guests, and passers-by.

For the daylighting quality, the same jury of lighting experts evaluated each team's ability to address the following important factors in its daylighting design and implementation:

- Human factors, including physiology, perception, preferences, and behavior,
- Effects of daylight on all materials, including furniture, artwork, and plants,
- Controlled admission of direct sunlight,
- Controlled admission of diffuse daylight, and
- Integration of building systems, including the electric lighting, fenestration, interior geometry and finishes, manual and automatic control systems, and active climate control systems.

The evening house lighting consisted of turning on all interior and exterior house lights between 7:30 p.m. and 9:30 p.m. On the other hand, the daytime workstation lighting required to provide light levels above 50 footcandles (538 lux) between 9 a.m. and 5 p.m. on 4 days of the contest week.

For these lighting areas or tasks, the TAMU team was well prepared for the evening and daytime areas. The evening house lights were all compact fluorescent fixtures with the intention of consuming less electricity and generating less heat. The daytime workstation was located in an area of the house surrounded by windows in order to prevent the use of an additional task light.

For the daylighting quality, the TAMU team performed extensive research (Section 3.3.3.), which helped design the shading in the south and west facades. Unfortunately, although exterior shading devices were designed; they were removed due to miscalculations in the loads that the house structure was able to hold. The use of the light wing implemented the use of diffuse daylight throughout the house and blinds were located in every window provided the daylight control of the space.

Unfortunately, the TAMU team had limited time to fully design all aspects of the electric lights. Therefore, although functional, the electric lighting design did not include different colors for different moods, no accentuation lights, and there was no lighting controlling device.

Energy balance

In the Energy Balance contest, teams whose houses produced as much energy as they consumed over the course of the continuously measured portion of contest week earned 100 points. For this contest the TAMU team prepared a schedule/worksheet that presented all the different tasks during the whole week of competition. This worksheet included all the estimated energy consumption depending of all the tasks taking place in the house. An example of this worksheet is presented on Figure 121. The same worksheet was prepared for every day of the contest week. It permitted the evaluation of what contest was more important to run depending on the amount of points available. For example, after monitoring the energy balance of the house for the first two days of the competition, the TAMU team had the option of running the HVAC unit to gain points on the comfort zone contest or to shut down the HVAC system and try to save energy for the overall energy balance.

Total		Daily					Time		Tasks		
Total pts.	Total tasks	Tasks day	Pts. day	kWh day	Task kWh day	kWh pt.	Monitoring time	Operation time	Loads	Operation	kW
50	336	96	14.29	26.40	26.40	1.85	1-24	1-24	Heat Pump	Always ON (heating or cooling, 74F setpoint)	1.10
50	336	96		19.20	19.20	N/A	1-24	1-24	Dehumidifier	ON if RH > 50% ^, ON during shower & water vap. test.	0.80
				0	-	N/A	-	-	ERV	Always OFF	0.10
30	396	96		12.00	12.00	N/A	1-24	1-24	Ref/ Freezer	Always ON (cycles) Tref.:34-40F, Tfr:-20-5F	0.50
10	2	0		0.00	0.00	N/A			Clothes Washer	Max. 2(or 1)-45 min. cycles	2.00
20	2	0		0.00	0.00	N/A			Dryer	Max. 2-90 min. cycles	3.00
10	4	1		3.00	3.00	N/A	9-15	11:30-14:00	Dishwasher	Max. 1-150 min. cycle	1.20
100	10	2	20.00	6.00	6.00	0.30	10-11 16-17	8-10 14-16	Shower (2 External Water Heaters)	For 10 min. (uses pr. pump energy + 15 gal. water from water heaters)	1.50
0	-	-	0.00	0.45	-	N/A	-	10-11 13-14 16-17	Pr. Pump	Always ON (Auto, after shower, and after CW+DW tests)	0.15
0	-	-	0.00	3.60	-	N/A	-	1-24	HVAC Circ. Pump	Always ON (Auto) for Solar thermal space heating	0.15
0	-	-	0.00	1.80	-	N/A	-	7-19	Solar Thermal Pump	Sunrise to sunset (Auto), if collector outlet temp - tank temp. > 7F	0.15
4	1		0.00	0.00	0.00	N/A			Cooktop	Before dinner, use rear burners, special lids	3.40
1	1		0.00	0.00	0.00	N/A			Microwave oven	To Thaw, Preheat, Reheat	0.90
15	3	1	5.00	4.40	4.40	0.88	8-10	8-10	Cooktop	Vaporize 5 gal.in < 2h, use rear large burner, special lid,	2.20
5	5	1	1.00	1.08	1.08	1.08	10-16	10-16	TV/ V	[illegible]	[illegible]
5	5	1	1.00	1.60	1.60	1.60	9-17	9-17	Comp	[illegible]	[illegible]
10	136	32	2.35	0.80	0.80	0.34	9-17	9-17	Daytim light	[illegible]	[illegible]
5	4	1	1.25	3.00	3.00	2.40	8-10	8-10	Evening Lighting	Total installed wattage (~3W/sq.ft.)	1.50
100	5	1	20.00	15.64	15.64	0.78	1-7 8:30-15:30	7-8:30 15:30-17	Car Charging	3.5 hr. recharge = 1.5 hrs. driving at 15mph (SOC 50-100%)	1.01
				98.97							20.14
											98.97

Loads	0-1				1-2				2-3				3-4				4-5				5-6			
	0:00	0:15	0:30	0:45	1:00	1:15	1:30	1:45	2:00	2:15	2:30	2:45	3:00	3:15	3:30	3:45	4:00	4:15	4:30	4:45	5:00	5:15	5:30	5:45
Heat Pump	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Dehumidifier	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
ERV																								
Ref/ Freezer	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Clothes Washer																								
Dryer																								
Dishwasher																								
Shower (2 External Water Heaters)																								
Pr. Pump																								
HVAC Circ. Pump	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Solar Thermal Pump																								
Cooktop																								
Microwave oven																								
Cooktop																								
TV/ V	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Comp	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Daytim light	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Evening Lighting																								
Car Charging	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009				
	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	2.55	2.55	2.55	2.55
	3.559				3.559				3.559				3.559				3.559				2.55			

Loads	6-7				7-8				8-9				9-10				10-11				11-12			
	6:00	6:15	6:30	6:45	7:00	7:15	7:30	7:45	8:00	8:15	8:30	8:45	9:00	9:15	9:30	9:45	10:00	10:15	10:30	10:45	11:00	11:15	11:30	11:45
Heat Pump	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Dehumidifier	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
ERV																								
Ref/ Freezer	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Clothes Washer																								
Dryer																								
Dishwasher																							1.2	1.2
Shower (2 External Water Heaters)									1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5								
Pr. Pump																	0.15	0.15	0.15	0.15				
HVAC Circ. Pump	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Solar Thermal Pump					0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Cooktop																								
Microwave oven																								
Cooktop									2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2								
TV/ V	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Comp	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Daytim light	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Evening Lighting																								
Car Charging											1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009
	2.55	2.55	2.55	2.55	2.70	2.70	2.70	2.70	6.40	6.40	7.41	7.41	7.71	7.71	7.71	7.71	4.34	4.34	4.34	4.34	4.19	4.19	5.39	5.39
	2.55				2.7				6.9045				7.709				4.339				4.789			

Loads	12-13				13-14				14-15				15-16				16-17				17-18			
	12:00	12:15	12:30	12:45	13:00	13:15	13:30	13:45	14:00	14:15	14:30	14:45	15:00	15:15	15:30	15:45	16:00	16:15	16:30	16:45	17:00	17:15	17:30	17:45
Heat Pump	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Dehumidifier	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
ERV																								
Ref/ Freezer	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Clothes Washer																								
Dryer																								
Dishwasher	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2																
Shower (2 External Water Heaters)									1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5								
Pr. Pump					0.15	0.15	0.15	0.15									0.15	0.15	0.15	0.15				
HVAC Circ. Pump	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Solar Thermal Pump	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Cooktop																								
Microwave oven																								
Cooktop																								
TV/ V	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18								
Comp	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2				
Daytim light	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1				
Evening Lighting																								
Car Charging							1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009				
	4.38	4.38	4.38	4.38	4.53	4.53	5.54	5.54	5.69	5.69	5.69	5.69	5.69	5.69	5.69	5.69	4.16	4.16	4.16	4.16	2.70	2.70	2.70	2.70
	4.38				5.0345				5.689				5.689				4.159				2.7			

Loads	18-19				19-20				20-21				21-22				22-23				23-24			
	18:00	18:15	18:30	18:45	19:00	19:15	19:30	19:45	20:00	20:15	20:30	20:45	21:00	21:15	21:30	21:45	22:00	22:15	22:30	22:45	23:00	23:15	23:30	23:45
Heat Pump	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Dehumidifier	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
ERV																								
Ref/ Freezer	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Clothes Washer																								
Dryer																								
Dishwasher																								
Shower (2 External Water Heaters)																								
Pr. Pump																								
HVAC Circ. Pump	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Solar Thermal Pump	0.15	0.15	0.15	0.15																				
Cooktop																								
Microwave oven																								
Cooktop																								
TV/ V																								
Comp																								
Daytim light																								
Evening Lighting					1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5												
Car Charging			1.009	1.009	1.009	1.009	1.009	1.009									1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009
	2.70	2.70	3.71	3.71	5.06	5.06	5.06	5.06	4.05	4.05	4.05	4.05	2.55	2.55	2.55	2.55	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56
	3.2045				5.059				4.05				2.55				3.559				3.559			

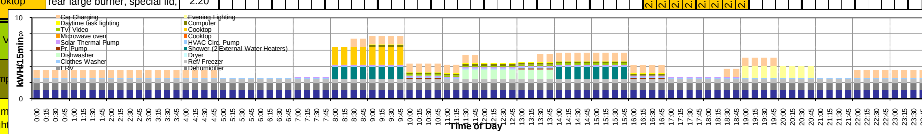


Figure 121: Schedule/ worksheet example.

Getting Around

Points were awarded on a daily basis for mileage credits earned. The team that accumulated the most mileage credits on each day of the contest week established the maximum mileage credits and received all available points for that day. The other teams received a percentage of the daily available points based on the maximum mileage recorded by the winning team. Each team was allowed to select its own driving route(s). After testing the car several times, the TAMU team decided that the way the car was driven was crucial. The strategy became to drive the car at a constant velocity of 15 miles per hour until the car was 30% discharged. This allowed the car to charge faster and draw a lower amount of power. Another part of the strategy was to have the lightest team members as drivers, to keep the right tire pressure in the tires, and to run the car in a flat area with a smooth texture. Unfortunately for the TAMU team, other teams applied better strategies for charging and running the car. This explanation will be presented in the following chapter.

Chapter 6: Outcome

Section 6.1. Results and Analysis

Overall

The final scores for the competition were obtained by summing all the scores obtained in each one of the ten contests. Table 11 shows the final ranking and scores for the competition. Figure 122 shows the final scores for all contests. The TAMU team finished first in the Appliances contest, eighth in Market Viability, and ninth in three other contests: Hot Water, Comfort Zone, and Getting Around. The TAMU team finished in 17th place overall, ahead of Kansas, Cornell, and Lawrence Tech. It is important to understand that a team's final place in a contest may mean a lot for the final outcome of the competition; on the other hand, it may not be significant. An example of this is that in the Market Viability contest, the TAMU team finished 8th and 12.2 points behind the leader. On the other hand, they finished 15th in the Lighting contest but only 14.972 points behind the leader. Hence, sometimes the position a team ended up in a particular contest might not be very relevant. Table 12 shows how the TAMU did in each contest in comparison with team that won the respective contest. The contests that had a large point difference between the leader and the other universities are the Architecture contest, Engineering, Communications, Getting Around, and Energy Balance. Therefore, for future reference, these contests might be considered the most important contests of the competition.

Table 11: Final standings of the SD 2007.

Rank	Overall	
1	Darmstadt	1024.85
2	Maryland	999.807
3	Santa Clara	979.959
4	Penn State	975.432
5	Madrid	946.298
6	Georgia Tech	945.183
7	Colorado	943.369
8	Montreal	906.835
9	Illinois	886.956
10	Texas	877.503
11	Missouri-Rolla	869.179
12	NYIT	852.775
13	MIT	833.302
14	Carnegie Mellon	832.506
15	Cincinnati	830.865
16	Puerto Rico	819.502
17	Texas A&M	808.765
18	Kansas	807.049
19	Cornell	780.44
20	Lawrence Tech	691.35

Rank	Architecture		Engineering		Market Viability		Communications		Lighting	
1	Darmstadt	193.25	Darmstadt	136.4	Illinois	114.35	Maryland	98.2	Darmstadt	95.455
2	Maryland	189.5	Texas	130.65	Maryland	112.5	Santa Clara	92.45	Maryland	92.75
3	Madrid	187.5	Colorado	130.25	Penn State	109.95	Penn State	90.4	Penn State	92.319
4	Georgia Tech	184.25	Montreal	127.75	Missouri-Rolla	109.55	Texas	87.5	Colorado	90.171
5	Cincinnati	181	Penn State	127.4	Darmstadt	107.5	Georgia Tech	83.9	Montreal	89.114
6	NYIT	175.75	Maryland	127.35	Santa Clara	106	Montreal	81.5	Madrid	89
7	Montreal	175.75	NYIT	121.85	Colorado	105	Cornell	79.95	Illinoois	88
8	Penn State	174.75	MIT	120.75	Texas A&M	102.15	Darmstadt	79.15	Santa Clara	85.734
9	Texas	174.25	Cornell	119.35	Georgia Tech	101.45	Lawrence Tech	78.3	Missouri-Rolla	84.994
10	Colorado	171	Santa Clara	119.15	Texas	101.2	Illinois	77.75	Kansas	84.5
11	Cornell	168.5	Illinois	114.75	Lawrence Tech	100.35	Puerto Rico	71	NYIT	83.496
12	Kansas	166	Georgia Tech	112.85	Carnegie Mellon	97	NYIT	69.6	Lawrence Tech	81.932
13	Puerto Rico	161.75	Madrid	111.75	NYIT	96.6	Missouri-Rolla	69.05	Puerto Rico	81.369
14	Illinois	154.5	Missouri-Rolla	111	Cornell	96.1	Kansas	66.4	Carnegie Mellon	81.151
15	Carnegie Mellon	153.5	Carnegie Mellon	110.25	Montreal	92	Cincinnati	65.5	Texas A&M	80.483
16	Texas A&M	152.75	Puerto Rico	109.65	Cincinnati	87.75	Madrid	65.35	Texas	78.967
17	Lawrence Tech	141	Kansas	109.25	Madrid	79.8	Texas A&M	64.7	Cornell	78.831
18	Santa Clara	123.75	Cincinnati	104.5	Puerto Rico	79.8	Colorado	63.5	MIT	78.5
19	MIT	120.5	Lawrence Tech	102.9	Kansas	77.3	MIT	61.2	Cincinnati	77.5
20	Missourri-Rolla	107	Texas A&M	100.85	MIT	70.7	Carnegie Mellon	60.7	Georgia Tech	74.5

Rank	Appliances		Hot Water		Comfort Zone		Energy Balance		Getting Around	
1	Teas A&M	98.191	Texas	100	Illinois	81.343	Santa Clara	100	Colorado	86.335
2	Santa Clara	93.767	Santa Clara	100	Montreal	77.852	MIT	100	Santa Clara	84.946
3	Darmstadt	89.206	Puerto Rico	100	Texas	75.716	Maryland	100	Georgia Tech	84.01
4	Madrid	85.697	Penn State	100	Maryland	75.215	Madrid	100	Puerto Rico	80.896
5	Missouri-Rolla	81.797	Kansas	100	Santa Clara	74.162	Darmstadt	100	Madrid	79.325
6	Kansas	81.448	Darmstadt	97.7	Missouri-Rolla	74.087	Cincinnati	100	MIT	70.377
7	Penn State	78.399	Missouri-Rolla	95.2	Madrid	73.377	Carnegie Mellon	100	Montreal	70.118
8	Montreal	76.442	Maryland	92.9	NYIT	71.594	Colorado	94.831	Illinoin	68.938
9	Puerto Rico	71.87	Texas A&M	90	Texas A&M	71.137	Missouri-Rolla	92.671	Texas A&M	58.504
10	Carnegie Mellon	67.922	Cincinnati	90	Darmstadt	70.945	Illinois	87.236	Lawrence tech	55.522
11	Lawrence Tech	65.77	Montreal	89.7	Carnegie Mellon	69.632	Georgia Tech	85.468	Kansas	55.445
12	Texas	63.749	Gergia Tech	88.3	Cornell	68.994	Penn State	83.942	Darmstadt	55.25
13	Georgia Tech	63.687	MIT	82.6	Penn State	67.587	NYIT	83.088	Maryland	54.766
14	MIT	61.171	Colorado	81	MIT	67.504	Texas	27.049	Penn State	50.684
15	Colorado	60.467	Madrid	74.5	Georgia Tech	66.768	Montreal	26.609	NYIT	48.42
16	Cornell	60.269	Cornell	71.3	Kansas	66.707	Kansas	0	Missouri-Rolla	43.829
17	Maryland	56.626	NYIT	66.8	Lawrence Tech	65.576	Lawrence Tech	0	Cincinnati	41.772
18	Illinois	51.389	Carnegie Mellon	56.5	Puerto Rico	63.167	Cornell	0	Texas	38.422
19	Cincinnati	38.237	Illinois	48.7	Colorado	60.816	Puerto rico	0	Cornell	37.146
20	NYIT	35.579	Lawrence Tech	0	Cincinnati	44.606	Texas A&M	0	Carnegie Mellon	35.85

Figure 122: Final rankings for each contest.

Table 12: TAMU team's points behind each contest leader.

Contest	Points Behind Leader
Architecture	40.5
Engineering	35.55
Market Viability	12.2
Communications	33.5
Lighting	14.972
Appliances	0
Hot Water	10
Comfort Zone	10.206
Energy Balance	100
Getting Around	27.831

HVAC System

During the contest week, the TAMU team confronted problems with the HVAC control system. The biggest concern was the system's operation during the night because there was nobody at the house to override the settings of the unit. The worst night of the contest week was the third night of the week (Wednesday to Thursday) since the system ran the dehumidifier all night. This raised the temperature above the partial point limits of the competition. Figure 123 and Figure 124 show the inside dry bulb temperature and relative humidity, respectively. These mistakes were costly, not necessarily for the comfort zone contest but for the energy balance contest. Other factors that did not help to keep the required levels were the excessive infiltration into the house and the heat gain through the exposed steel beams and columns of the house. Although the design called for insulated cladding these hollow steel beams and columns were not insulated or covered with a material that reduced the conduction heat transfer through the steel. During the first three nights of the contest week, this contributed to the heat loss the night. Figure 130 shows the outside temperature and relative humidity for the National mall. Another problem with the HVAC system was the improper location of the thermostat/humidistat which was attached to an uninsulated steel beam. On the bright side, condensation on the un-insulated duct never occurred. For future consideration, if the Energy Balance contest is slipping away from the full-points range and the team needs to sacrifice points from another contest in order to save energy, disabling the air conditioning unit is the best way to go (with the system used at the TAMU house).

Refrigerator and Freezer

The monitored data for the refrigerator and freezer temperature is in Figure 125 and Figure 126 respectively. For the refrigerator, the data was steady at almost all times with the exception of four data points where it was too cold or too hot. The points where the temperature was too high were during times when team members opened the door of the refrigerator for cooking activities. The reason for the low temperature points remains unknown. The data related with the temperature inside the freezer was also steady. At the beginning of the contest week the temperature set point was -6 degrees Fahrenheit but after the first day, it was changed to 2 degrees Fahrenheit, which would accomplish full credit and save on valuable electricity.

Indoor Light

The data for indoor lighting is shown in Figure 127. The light levels were inside the desired ranges for the first three days of the contest using daylighting only. During the fourth day, in the afternoon, clouds covered the solar village and the lighting level went under the desired range. In addition to this, the person in charge of supervising the sensor during tour hours left, leaving the sensor exposed to curious visitors that shaded the light sensor during several minutes. On the last morning of the competition, the east side shading device broke, which took around 20-30 minutes to fix the problem.

Energy Balance

The energy balance data from the competition is shown in Figure 128. This figure shows how the TAMU solar electrical system performed during the contest week. During the first day of the competition, the TAMU system produced approximately 5.5KWh (compared to 15KWh from most teams) and was able to barely remain above the required level in order to get full points in the contest. However, the nighttime consumption of the house was substantial due to the car charging strategy and on the second day it was clear that something was horribly wrong with the system. When the energy produced on the first day of contest was compared with the energy produced the second day, it was clear that the amount of energy produced the second day was less than half the production of the first day. About the only thing the team could do was to check the available solar radiation on the two days. The data for the global horizontal insolation is available in Figure 131. This figure shows that the difference in incident radiation was not very substantial. Therefore, by the third day the team realized something definitely had happened with the PV system array. However, it was not until after the competition was finished that the TAMU team was able to realize that a breaker for a section corresponding to about 1/3 of the total PV array had tripped, which meant the house was definitely consuming more energy than what the PV system was producing. A proof of this is Figure 129 which shows the decrease in the battery bank voltage. From the afternoon of the fourth day of the contest week, the TAMU house ran out of power under the recommended charge level. To remedy this, the team changed the set-point for minimum voltage from 42 volts to 36 volts. From this time on, all appliances in the house were disconnected with the exception of the refrigerator/freezer, the main supply pump, and the car charger.

It is important to mention that several teams had the capability of producing 10-15 kWh in one day in comparison with approximately 6 kWh from the TAMU house, which means that the 14% efficient panels from the TAMU team was not able to compete with 20-22% efficient panels from other teams. A significant contribution to this situation was the fact that more than one half of the TAMU panels where not tilted to optimum angle.

If the HVAC system would have been turned off after the first night of the competition, the TAMU team might have obtained full-point on the Energy Balance contest. On the other hand, it is difficult to predict what would have happened with the Comfort zone contest. In the future it is recommended that careful attention be paid to each and every appliance and that a wireless, internet control monitoring system be designed and installed to better determine problems as they occur.

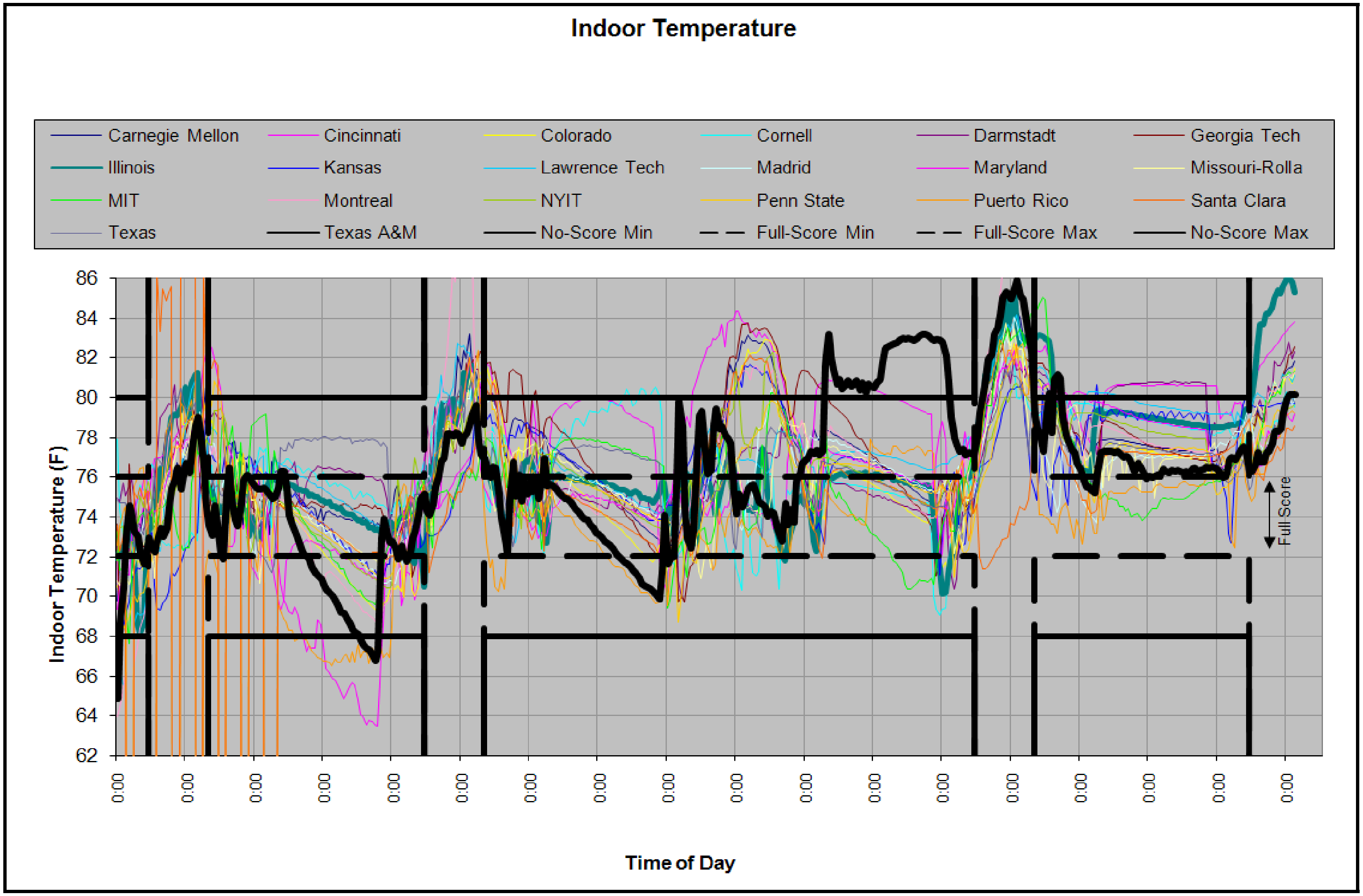


Figure 123: Indoor dry-bulb temperature.

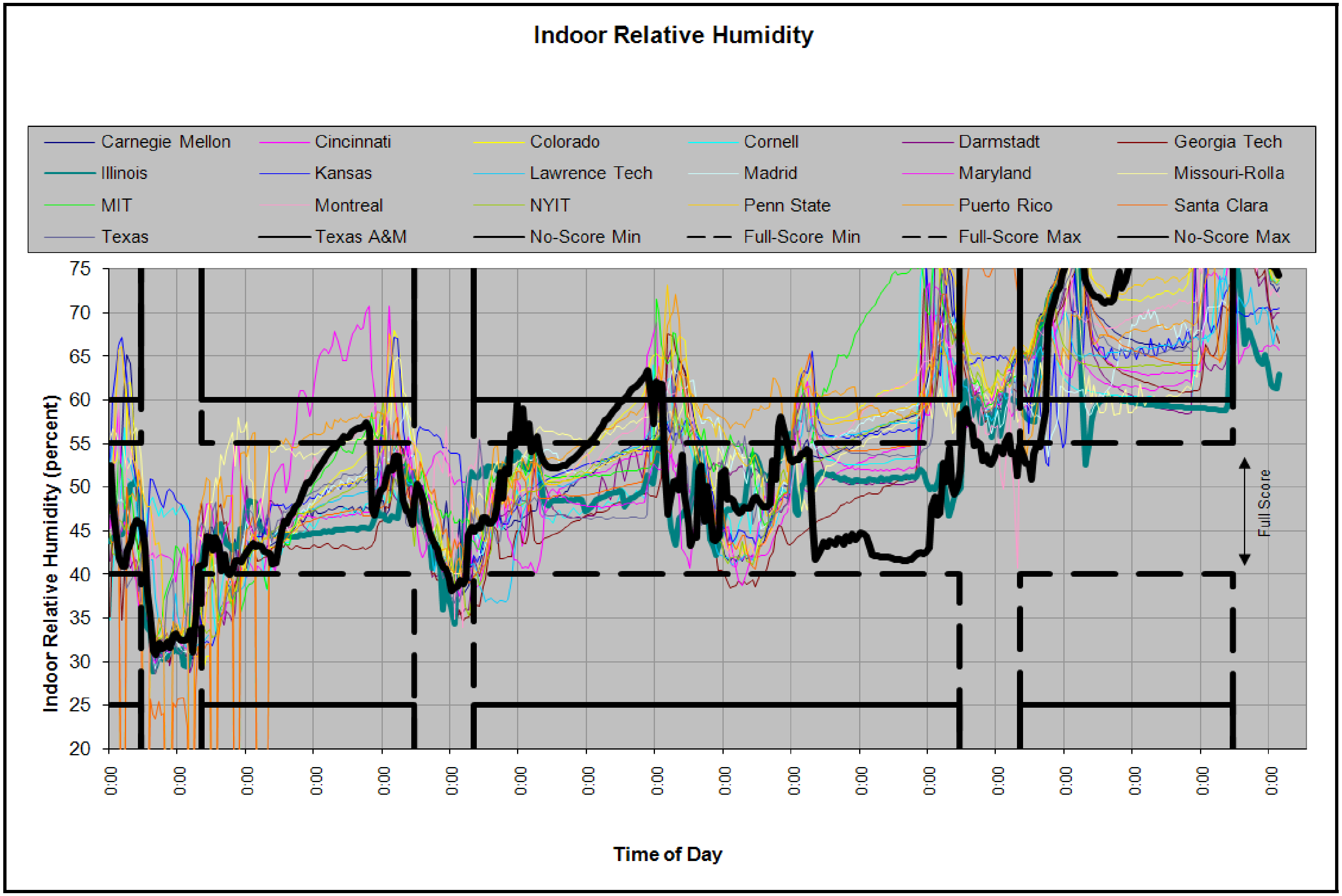


Figure 124: Indoor relative humidity.

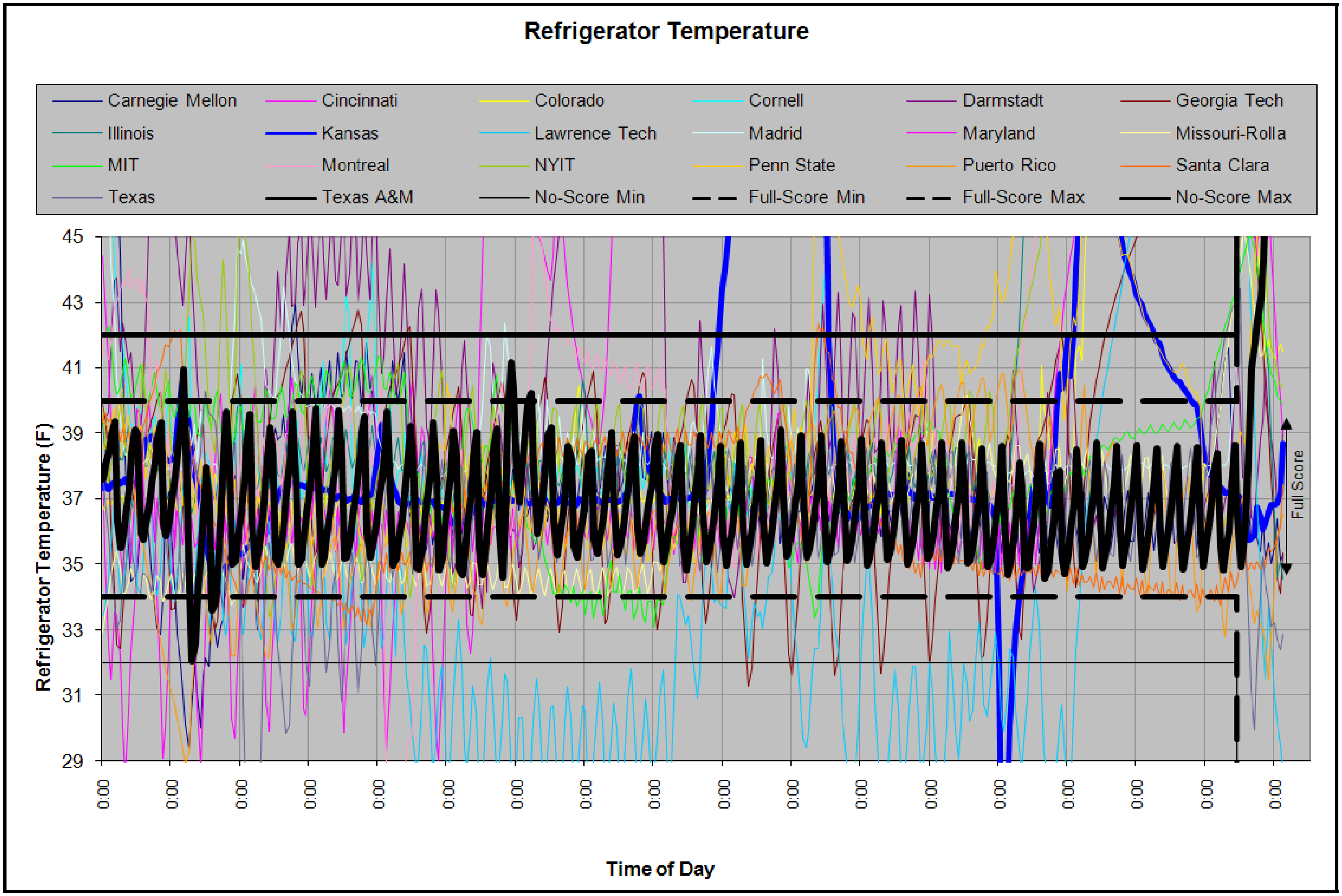


Figure 125: Refrigerator temperature.

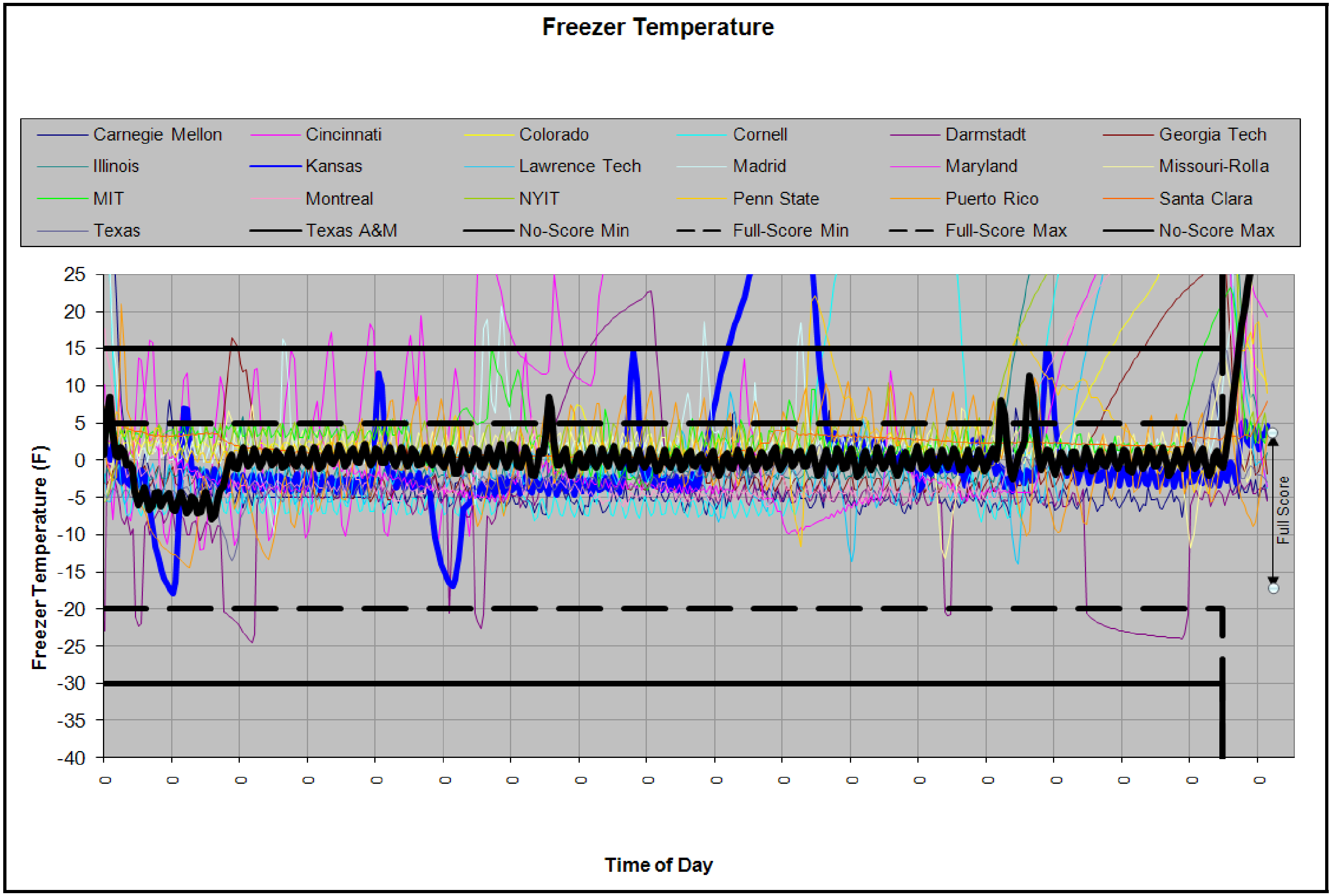


Figure 126: Freezer temperature.

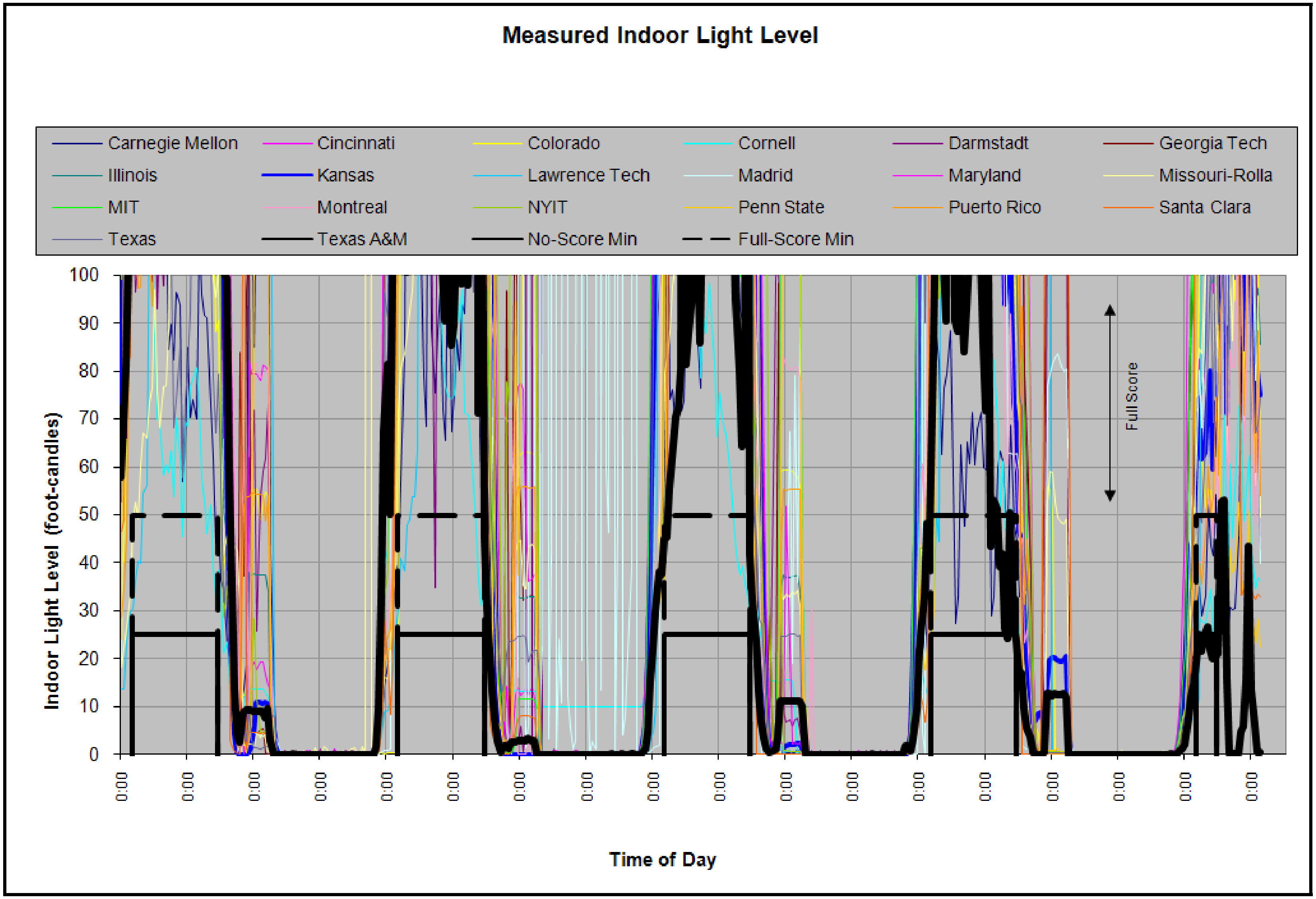


Figure 127: Indoor light levels.

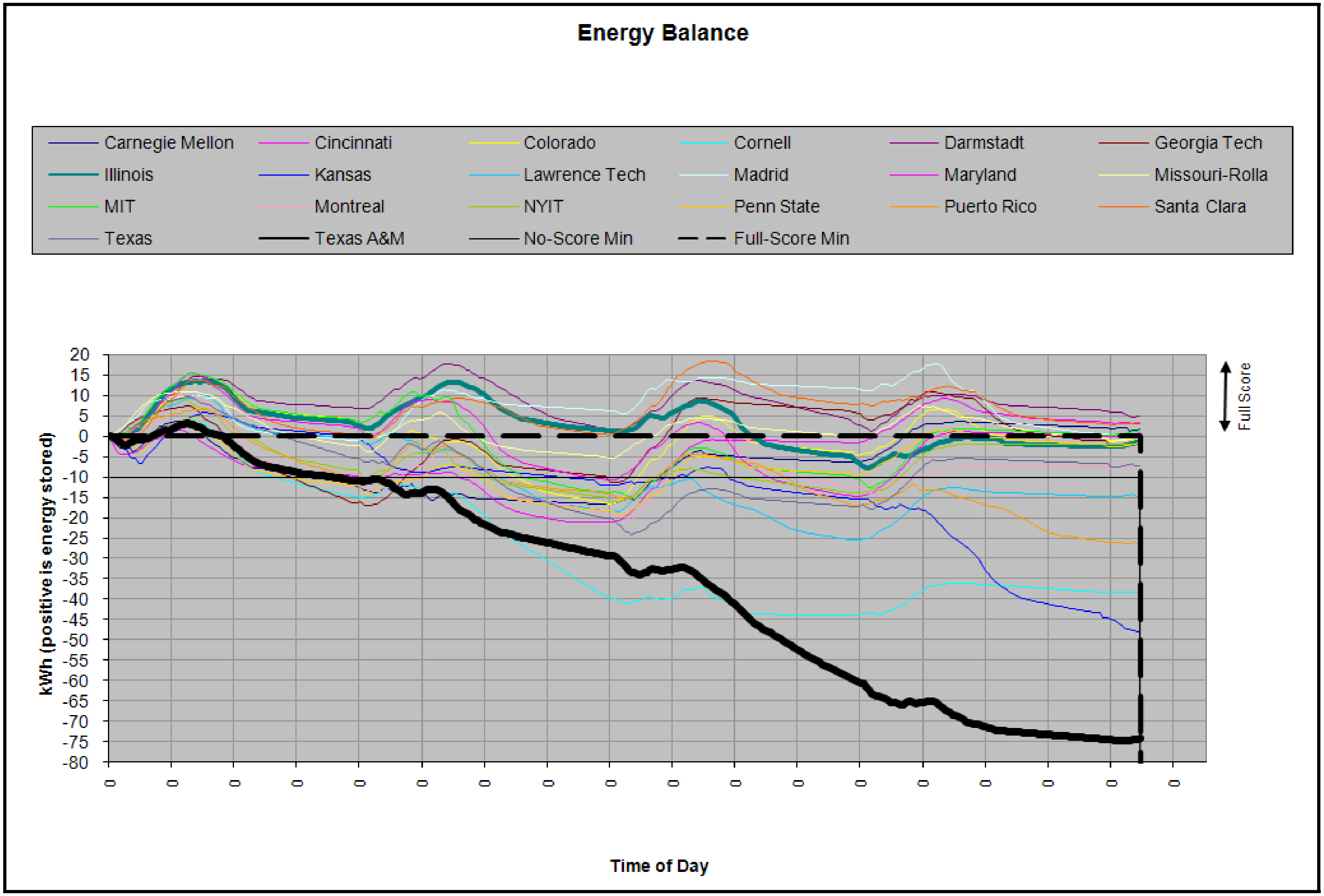


Figure 128: Energy balance contest scores.

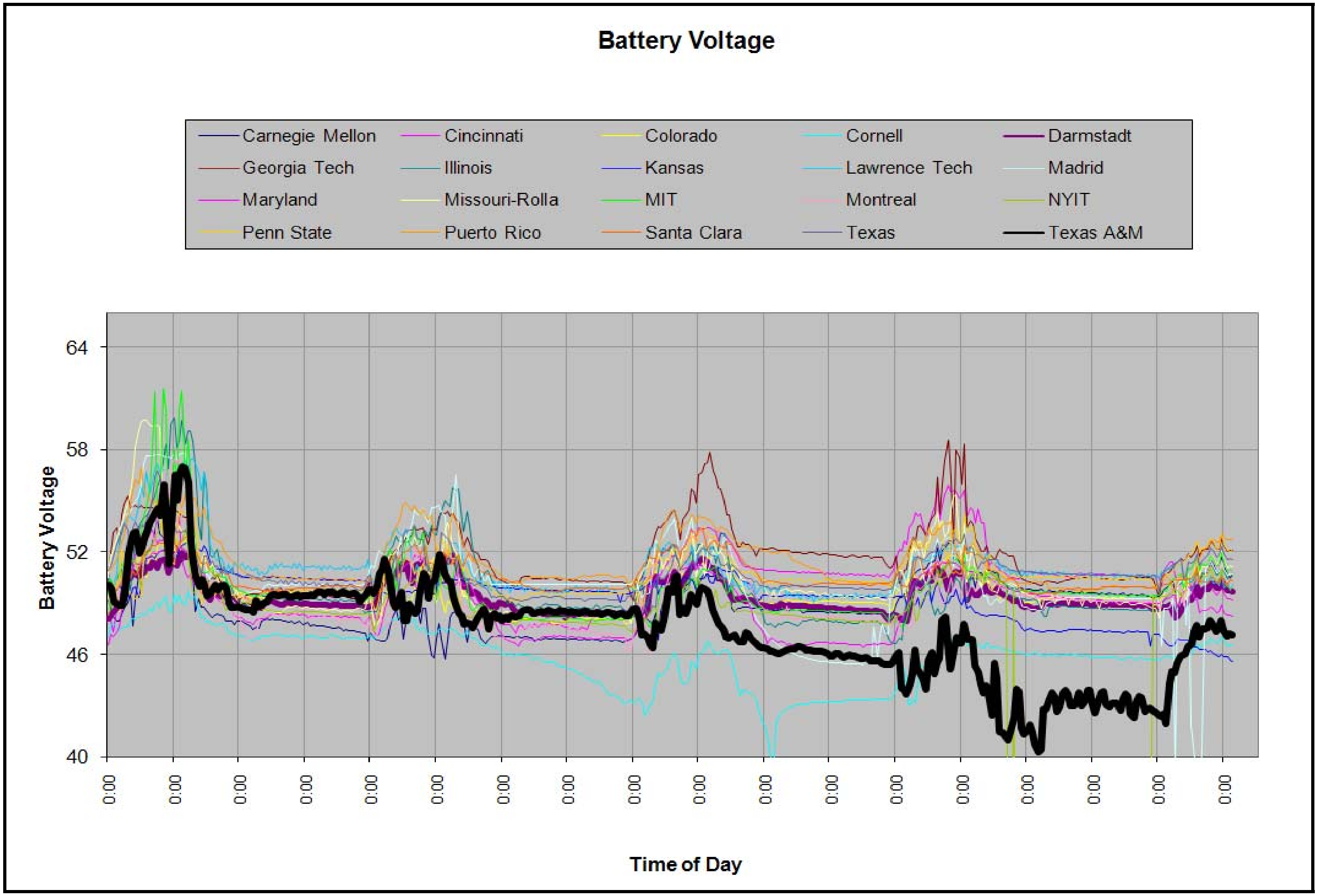


Figure 129: Battery bank voltage.

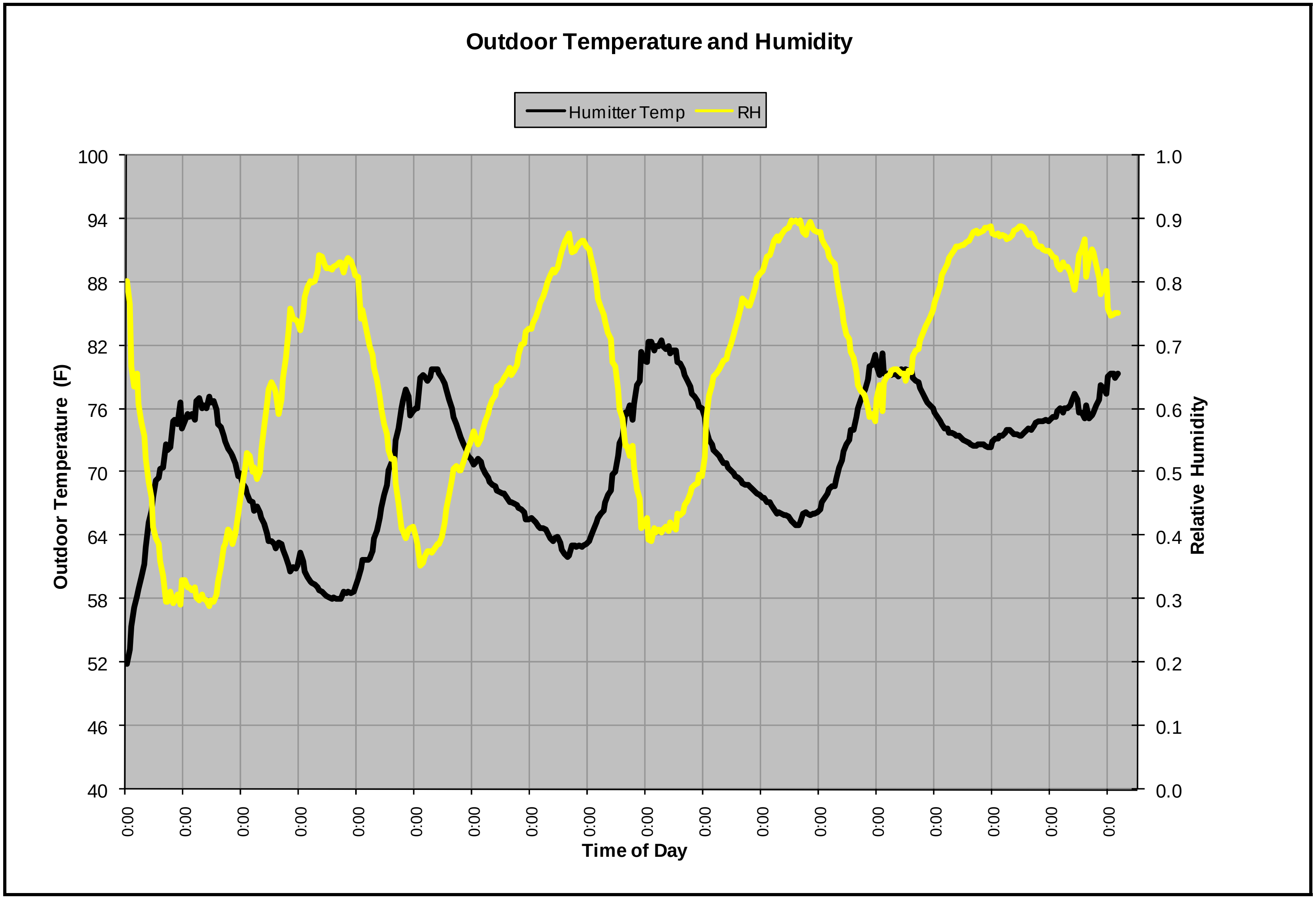


Figure 130: Outdoor temperature and relative humidity for the National Mall.

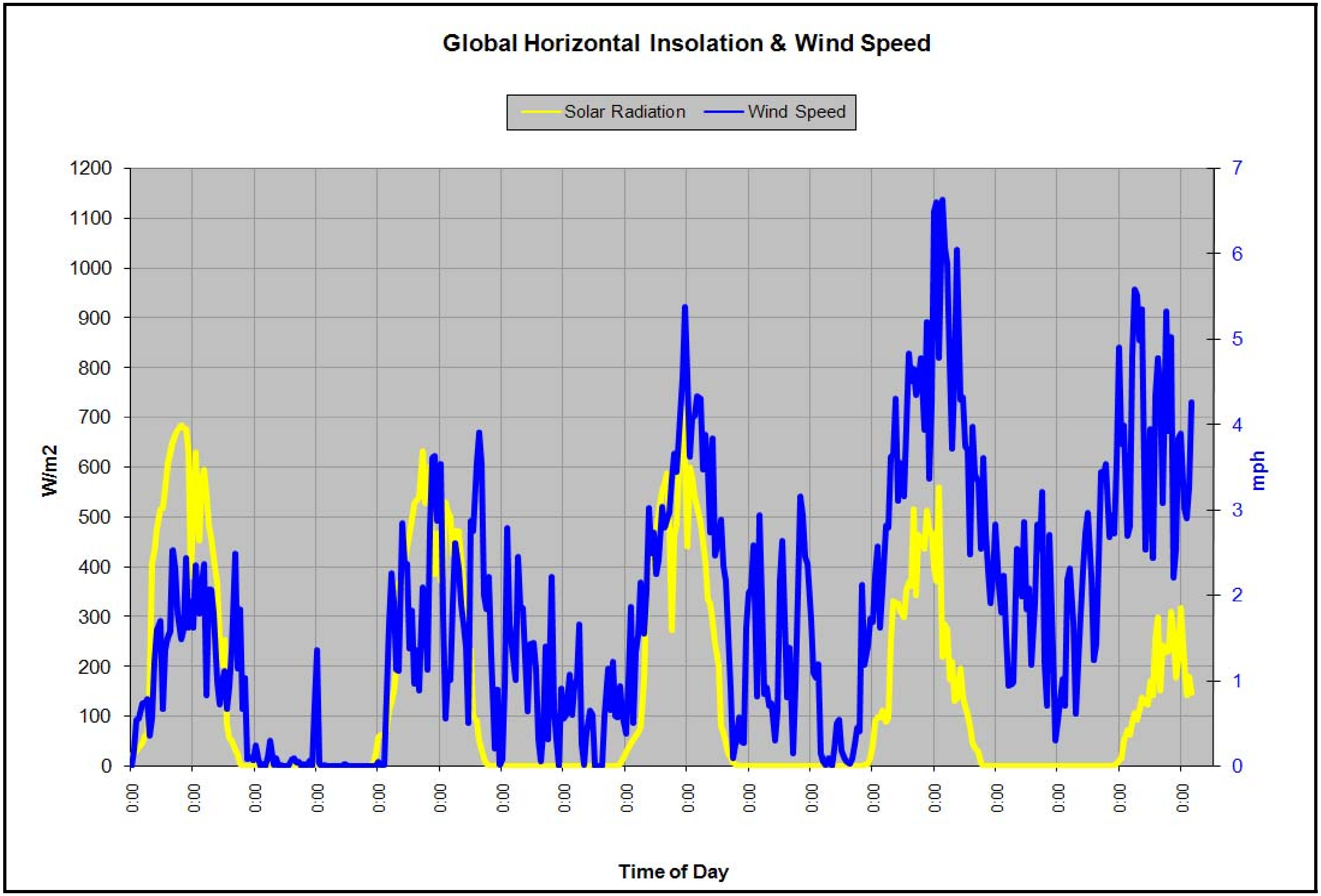


Figure 131: Global horizontal radiation and wind speed for the National Mall.

Section 6.2. Conclusions and Recommendations

The Solar Decathlon is a complex interdisciplinary project that requires teamwork and communication especially during the integration of different areas such as architecture and engineering. It is known that there is no formula for building a perfect solar house. However, with a good concept and integrated design it is possible to make solar work in an intelligent matter.

To win a Solar Decathlon it is important to succeed, particularly in the subjective contests of the competition since their evaluation may create point leads that are impossible to overcome. It is important to understand that it is improbable to win all the contests of the competition and a team only wins if provides an overall superior design and operation. This is possible to achieve with several features. The first feature is to start with a good core of faculty, staff, and students that will commit to the entire project. The second feature is to be well organized as a team, establishing specific roles for every team member and having a master plan of goals through the two years of the project. The third point is to have the passion and competitive nature within the team so that everybody tries to go beyond the expectations on the different house components. The fourth feature is to have more-than-adequate fund raising so superior components can be purchased and, if needed, assistance from professionals.

This project was a learning experience for everyone involved in it, and, after the experience, there are recommendations that may improve the designs of future solar homes. For the architecture of the house, it is important to provide a design that minimizes the amount of labor at the National Mall. Usually, houses that have won the competition had been look-alike houses that were easy to assemble and control. The finishes of the interior and exterior facades are also crucial since they prove how much attention to detail and how well-organized a team was at the time of designing and constructing the house. Finally, there should be a good communication between the architects and engineers inside the team so that the integration of engineering systems and architectural design satisfies all the contest requirements. From the engineering side, the use of electricity at times when the sun is not available should be avoided. Ideas such as thermal storage, high R-values, low infiltration, and high efficiency systems could be combined together for a better design. PV technology is getting better every day and panels are more efficient. Therefore, the importance of using the most efficient PV panels available, at the right angle, can't be ignored. The difference between having 22% efficient panels and 14% efficient panels makes a big difference for a team's outcome in the competition. With low efficiency panels is very hard to maintain a balance between the energy consumption and the energy production. The use of direct power (DC) motors could result in some energy savings. The problem with doing this is that it will require a more complicated electrical wiring throughout the house (i.e., two different wiring systems). Another idea that would cut the energy losses is to implement a small inverter to the photovoltaic BOS so that direct power can be converted to AC power without passing through the efficiency losses at the battery bank. For the HVAC system, the use of thermal (cooling and heating) storage is almost a must do scenario for future solar houses. This minimizes the excessive energy consumption during the night. Passive ventilation might also be part of the picture. However, it is important to realize that it does not work for all climates due to relative humidity issues.

Finally, the main problem with solar power and new technology is the first cost of the systems. It was clearly visible at the National Mall that certain houses had more money than others. Some teams opted to purchase the most efficient PV panels vs. using donated, lower efficiency PV panels. This aspect should be balanced in the Market Viability contest. However, it is clear that having a maximum amount of money provides a team with more choices for higher efficiency panels, equipment, and control systems.

Chapter 7: References

- Blateyron, F. (2006). *Shadows Version 2.2.5*. Retrieved March 13, 2007, from www.shadowspro.com.
- Brandhorst, H. (2003). The Auburn University Solar Decathlon House. *1st International Energy Conversion Engineering Conference* (pp. 1-6). Portsmouth, Virginia: American Institute of Aeronautics and Astronautics.
- Briggs, R., Lucas, R., & Taylor, T. (2003). Climate Classification for Building Energy Codes and Standards: Part 1 - Development Process. *ASHRAE Winter Meeting.* Chicago, IL: ASHRAE.
- Briggs, R., Lucas, R., & Taylor, T. (2003). Climate Classification for Building Energy Codes and Standards: Part 2 - Zone Definitions, Maps and Comparisons. *ASHRAE Winter Meeting.* Chicago, IL: ASHRAE.
- Charron, R. & Athienitis, A. (2006). Design and Optimization of Net Zero Energy Solar Homes. *ASHRAE Transactions*, Volume 112, Part 2.
- Charron, R., Athienitis, A., & Beausoleil-Morrison, I. (2005). Tools for the Design of Zero Energy Solar Homes. *30th Annual Conference of the Solar Energy Society of Canada.* Vancouver.
- Choudhary, R., Augenbroe, G., Gentry, R., & Hu, H. (2007). Simulation Enhanced Prototyping of an Experimental Solar House. *10th International Building Performance and Simulation Association Conference* (pp. 1690-1697). IBPSA.
- Chuku, A., Oni, B., Armstrong, D., Safavi, M., & Burge, L. (2003). Integrated Engineering Eduacational Through Multi-Disciplinary Nationally Relevant Projects: The Solar Decathlon Project. *American Society for Engineering Education Annual Conference and Exposition* (p. Session 2632). American Society for Engineering Education.
- DOE, U. (2006, 03 09). Retrieved February 20, 2008, from Building Energy Codes Resource Center: http://resourcecenter.pnl.gov/cocoon/morf/ResourceCenter/article/1420
- Eastment, M., Hayter, S., Nahan, R., Stafford, B., Warner, C., Hancock, E., et al. (2004). *Solar Decathlon 2002: The Event in Review.* U.S. Department of Energy Office of Energy Efficiency and Renewable Energy.
- Ellis, M. (2003). Multi-Disciplinary teaching and Learning in a Senior Project Course. *American Society for Engineering Education Annual Conference and Exposition* (p. Session No. 2366). American Society for Engineering Education.
- Haberl, J. & Cho, S. (2004). *Literature Review of Uncertainty of Analysis Methods (F-CHART Program).* Report to the Texas Commission on Environmental Quality, ESL-TR-04-08-04.

- Haberl, J. & Cho, S. (2004). *Literature Review of Uncertainty of Analysis Methods (PV F-CHART).* Texas Comission on Environmental Quality, ESL-TR-04-10-02.
- Hendron, R. (2005). *Building America Research Benchmark Definition, NREL/TP-550-37529.* Golden, Colorado: National Renewable Energy Laboratory.
- Huang, J. (2002). DrawBDl, Version 2.02. Joe Huand and Associates, 6720 Potrero Ave., El Cerrito, California 94530-2248.
- Klein, S. & Beckman, W. (1983). *F-CHART Solar Energy System Analysis: Version 5. F-CHART Software.* 4406 Fox Bluff Road, Middleton, Wisconsin, 53562: www.F-CHART.com.
- Klein, S. & Beckman, W. (1985). *PV F-CHART User's Manual, DOS Version 3.3, F-CHART Software.* 4406 Fox Bluff Road, Middleton, Wisconsin, 59562: www.F-CHART.com.
- Lawrence Berkeley National Laboratory, Building Technologies Department. (2003). Radiance Version 3.5. 1 Cyclotron Rd., 90-3111, Berkeley, California, 94720, USA.
- Marsh, A. (2005). *ECOTECT Version 5.5.* 53 Empress Terrace Central Promenade, Douglas, IM2 4EE, Isle Man, British Isles: Square One research LTD.
- Moon, S., Nahan, R., Warner, C., & Wassmer, M. (2006). *Solar Decathlon 2005: The Event in Review.* U.S. Department of Energy.
- National Research Council Canada. (2006). DAYSIM. Canada.
- National Renewable Energy Laboratory. (2007, February 16). *Solar Decathlon Rules and Regulations*. Retrieved February 9, 2008, from Solar Decathlon: www.solardecathlon.org/pdfs/sd07_rules_regs.pdf
- Pasini, M. & Athienitis, A. (2006). Systems Design of the Canadian Solar Decathlon House. *ASHRAE Transactions*, Volume 112, Part 2.
- Safavi, M. & Strueber, J. (2004). The Tuskegee University Solar Decathlon House Entry: A Critical Assessment. *American Society of Engineering Education Annual Conference and Exposition* (p. Session No. 1793). American Society of Engineering Education.
- Star, E. (2006). *Energy Star Qualified Products.*
- Warner, C. & Wassmer, M. (2006). Solar Decathlon 2005-PV System Strategies and Results. *4th World Conference on Photovoltaic Energy Conversion* (pp. 2272-2276). IEEE.
- Wassmer, M. & Warner, C. (2005). Building-Energy Simulation and Monitoring research Activities for Solar Decathlon Houses. *Photovoltaic Specialists Conference* (pp. 1714-1717). IEEE.
- Ward, G. (2006). Photosphere 1.7. 1200 Dartmouth St. #C, Albany, California, 94706-2358, USA.
- Yezioro, A., Dong, B., & Leite, F. (2008). An Applied Artificial Intelligence Approach Towards Assessing Building Performance Simulation Tools. *ScienceDirect, Energy and Buildings 40*, 612-620.

Appendix A - DOE2.1e simulation input

```
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$                                       Department of Architecture
$                                       Energy Systems Laboratory
$                                       Texas A&M University, College Station, TX 77843
```

```
##WRITE
##SHOWDETAIL

##SET1 LOCATION HOUSTON       $ INPUT1: HOUSTON/PHOENIX/STERLING
##SET1 MODEL PROTOTYPE        $ INPUT2: BENCHMARK/PROTOTYPE

$ LOCATION will determine the following:
$ 1. HEATON and COOLON (Seasons when Heating and/or cooling are active)
$ 2. DRAPE-SH-SCHEDULE (Drape shading schedule based on heating and cooling season)
$ 3. ALTITUDE, TIME-ZONE, DHW-INLET-T-SCHEDULE
$ 4. Benchmark wall, roof, floor and window and door U-values, window SHGC, ACH (infiltration)
$ 5. DHW-GAL/DAY (Daily hot water usage)
$
$ MODEL (PROTOTYPE/BENCHMARK) will determine the following:
$ 1. Lighting budget
$ 2. Equipment loads
$ 3. DHW gal/day
$ 4. Wall, roof and floor constuction (type and framing factor)
$ 5. window and door characteristics, ACH (infiltration)
$ 5. HVAC and DHW system efficiency
$
```

```
$ **********************************************
$ BENCHMARK PLAN: 18% WINDOW TO FLOOR AREA RATIO             _____________
$ **********************************************            [             ]
$                                                           [    BED      ]
$     [==============================================DDDDD==[. . . . . . .]======]
$     [                    `                    `          `                     W
$     [                    `                    `          `                     W
$     W                    `                    `          `                     W
$     W                    `                    `          `                     W
$     W 4'-2" X 5'-0"      `                    `          `                     W 4'-2" X 5'-0"
$     W                    `                    `          `                     ]=====]
$     W                    `                    `          `                     .     ]
$     [                    `                    `          `                     . LAUNDRY
$     [                    `                    `          `                     ======]
$(0,0)[=` ` ` ` ` ` ` ` ` ` ===` ` ` ` ` ` ` ` ` ` ======DDDDD==[` ` ` ` ` ` ` ` ` ]-]
$      [    KITCHEN       ] [   EDUTAINMENT    ]           [      BATH        ]
$      [==================] [===================]           [==================]
$
$________________
$  PLAN AT 4 FT.
$----------------                                            _____________
$                                                           [             ]
$                              10'-4" X 2'-0"               [    BED      ]
$     [====================WWWWWWWWWWWWWWWWWWWWWW================================]
$     [                    `                    `          `                     ]
$     [                    `                    `          `                     ]
$     [                    `                    `          `                     ]
$     [                    `                    `          `                     ]
$     [                    `                    `          `                     ]
$     [                    `                    `          `                     ]_____
$     [                    `                    `          `                     ]     |
$     [                    `                    `          `                     ] LAUNDRY
$     [                    `   10'-4" X 2'-0"   `          `                     ]_____|
$(0,0)[====================WWWWWWWWWWWWWWWWWWWWWW================================]
$      |    KITCHEN       | |   EDUTAINMENT    |           |       BATH       |
$      |__________________| |__________________|           |__________________|
$
$________________
$  PLAN AT 4 FT.
$----------------
$
$
$ ***************************************
$ PROTOTYPE PLAN: WINDOW AREA AS PROPOSED                    _____________
$ ***************************************                   [             ]
$                                                           [    BED      ]
$     ==WWWWWWWWWWWWWWWWWWW===WWWWWWWWWWWWWWWWWW===WW=DDDDD==[. . . . . . .]=DDDD=]
$     W                    `                    `          `                     ]
$     W                    `                    `          `                     ]
$     W                    `                    `          `                     ]
$     W                    `                    `          `                     ]
$     W                    `                    `          `                     ]
$     W                    `                    `          `                     ]=====]
$     W                    `                    `          `                     .     ]
$     W                    `                    `          `                     . LAUNDRY
$     W                    `                    `          `                     ======]
$(0,0)==` ` ` ` ` ` ` ` ` ===` ` ` ` ` ` ` ` ` ` ===WW=DDDDD==[` ` ` ` ` ` ` ` ` ]-]
$      [    KITCHEN       ] [   EDUTAINMENT    ]           [      BATH        ]
$      [WWWWWWWWWWWWW======] [=======WWWWWWWWWW=]           [==================]
$
$________________
$  PLAN AT 4 FT.
$----------------                                            _____________
$                                                           [             ]
$                                                           [    BED      ]
$     ==WWWWWWWWWWWWWWWWWWWW===WWWWWWWWWWWWWWWWWWW===WWWWWWW===WWWWWWWWWWWWWWWWWWWW==
$     W                    `                    `          `                     W
$     W                    `                    `          `                     W
$     W                    `                    `          `                     W
```

```
$     W                    `                    `          `                     W
$     W                    `                    `          `                     W
$     W                    `                    `          `                     W_____
$     W                    `                    `          `                     W     |
$     W                    `                    `          `                     W LAUNDRY
$     W                    `                    `          `                     W_____|
$(0,0)==WWWWWWWWWWWWWWWWWW===WWWWWWWWWWWWWWWWWW===WWWWWWW---WWWWWWWWWWWWWWWWWWW==
$      |    KITCHEN       | |   EDUTAINMENT    |            |       BATH        |
$      |__________________| |__________________|            |___________________|
$
$_______________
$  PLAN AT 4 FT.
$---------------
$
$**************************************
INPUT LOADS  INPUT-UNITS = ENGLISH
             OUTPUT-UNITS = ENGLISH  ..

TITLE           LINE-1 *TAMU SOLAR DECATHLON 2007* ..

##IF #[MODEL[] EQS BENCHMARK]
       SET-DEFAULT FOR EXTERIOR-WALL SHADING-SURFACE = NO  ..   $ BARB, p.7
##ELSEIF #[MODEL[] EQS PROTOTYPE]
       SET-DEFAULT FOR EXTERIOR-WALL SHADING-SURFACE = YES  ..
##ENDIF

RUN-PERIOD
       JAN 1 2007 THRU DEC 31 2007  ..
DIAGNOSTIC
       WARNINGS
       NO-ECHO
       LIMITS
       SINGLE-SPACED  ..
ABORT  ERRORS  ..

$****************************LOAD REPORTS********************************************************
LOADS-REPORT
       VERIFICATION = (ALL-VERIFICATION)
       SUMMARY      = (ALL-SUMMARY)
       ..
$**************************************
##IF #[LOCATION[] EQS HOUSTON]
       ##SET1 ALT 8
       ##SET1 T-Z = 6
##ELSEIF #[LOCATION[] EQS PHOENIX]
       ##SET1 ALT 68
       ##SET1 T-Z = 6
##ELSEIF #[LOCATION[] EQS STERLING]
       ##SET1 ALT 68
       ##SET1 T-Z = 7
##ENDIF
$**************************************
##SET1 NL 0.57                                $ NORMALIZED LEAKAGE, ASHRAE 136
##IF #[LOCATION[] EQS HOUSTON]
        ##SET1 WALL-U 0.085
        ##SET1 ROOF-U 0.041
        ##SET1 FLOOR-U 0.07
        ##SET1 WALL-INS-R 13.39
        ##SET1 ROOF-INS-R 25.47
        ##SET1 FLOOR-INS-R 13.59
        ##SET1 WALL-STUD-TH 0.2917
        ##SET1 ROOF-STUD-TH 0.4583
        ##SET1 FLOOR-STUD-TH 0.4583
        ##SET1 GLASS-U-BM 0.7617
        ##SET1 GLASS-SC-BM 0.8579
        ##SET1 ACH-BM #[NL[] * 0.81]

##ELSEIF #[LOCATION[] EQS PHOENIX]
        ##SET1 WALL-U 0.085
```

```
        ##SET1 ROOF-U 0.043
        ##SET1 FLOOR-U 0.07
        ##SET1 WALL-INS-R 13.39
        ##SET1 ROOF-INS-R 23.72
        ##SET1 FLOOR-INS-R 13.59
        ##SET1 WALL-STUD-TH 0.2917
        ##SET1 ROOF-STUD-TH 0.4583
        ##SET1 GLASS-U-BM 0.7617
        ##SET1 GLASS-SC-BM 0.8579
        ##SET1 FLOOR-STUD-TH 0.4583
        ##SET1 ACH-BM #[NL[] * 0.68]

##ELSEIF #[LOCATION[] EQS STERLING]
        ##SET1 WALL-U 0.058
        ##SET1 ROOF-U 0.030
        ##SET1 FLOOR-U 0.05
        ##SET1 WALL-INS-R 21.61
        ##SET1 ROOF-INS-R 41.60
        ##SET1 FLOOR-INS-R 22.43
        ##SET1 WALL-STUD-TH 0.4583
        ##SET1 ROOF-STUD-TH 0.4583
        ##SET1 FLOOR-STUD-TH 0.4583
        ##SET1 GLASS-SC-BM 0.3866
        ##SET1 GLASS-U-BM 0.53
        ##SET1 ACH-BM #[NL[] * 0.82]
##ENDIF
$*************************************
##IF #[LOCATION[] EQS HOUSTON]
       ##SET1 Fs 1.11
       ##SET1 EQ-S-BM 0.6349
       ##SET1 EQ-L-BM 0.0775
       ##SET1 GAL/DAY-BM 39.91
       ##SET1 GAL/DAY-PT 26.01

##ELSEIF #[LOCATION[] EQS PHOENIX]
       ##SET1 Fs 1
       ##SET1 EQ-S-BM 0.6336
       ##SET1 EQ-L-BM 0.0779
       ##SET1 GAL/DAY-BM 37.94
       ##SET1 GAL/DAY-PT 24.04

##ELSEIF #[LOCATION[] EQS STERLING]
       ##SET1 Fs 1
       ##SET1 EQ-S-BM 0.6336
       ##SET1 EQ-L-BM 0.0779
       ##SET1 GAL/DAY-BM 43.16
       ##SET1 GAL/DAY-PT 29.26
##ENDIF
$*************************************

##IF #[MODEL[] EQS BENCHMARK]
       ##SET1 LT-KWH/YR 1007.67
       ##SET1 EQ-KWH/YR #[2000.72 + #[2018.76 * Fs[]]]
       ##SET1 GAL/DAY GAL/DAY-BM[]
        ##SET1 EQ-S EQ-S-BM[]
        ##SET1 EQ-L EQ-L-BM[]
##ELSEIF #[MODEL[] EQS PROTOTYPE]
       ##SET1 LT-KWH/YR 700                 $ PROVIDE VALUE
       ##SET1 EQ-KWH/YR 2500                $ PROVIDE VALUE
       ##SET1 GAL/DAY GAL/DAY-PT[]
        ##SET1 EQ-S EQ-S-BM[]               $ PROVIDE VALUE
        ##SET1 EQ-L EQ-L-BM[]               $ PROVIDE VALUE
##ENDIF
$*************************************

##IF #[MODEL[] EQS BENCHMARK]
       ##SET1 WALL-ABS 0.5           $ BENCHMARK=0.5, DEFAULT=0.7
       ##SET1 WALL-EMT 0.9           $ BENCHMARK=0.9
       ##SET1 WALL-RGH 1             $ 1=STUCCO, 3(DEFAULT)=CONCRETE(POURED)
```

```
       ##SET1 ROOF-ABS 0.75          $ BENCHMARK=0.75, DEFAULT=0.7
       ##SET1 ROOF-EMT 0.9           $ BENCHMARK=0.9
       ##SET1 ROOF-RGH 1             $ 1=BUILT-UP ROOF W/ STONES, 3(DEFAULT)=ASPHALT SHINGLES
       ##SET1 FLOOR-ABS 0.5          $ N/A, DEFAULT=0.7
       ##SET1 FLOOR-EMT 0.9
       ##SET1 FLOOR-RGH 1            $ 3(DEFAULT)=CONCRETE(POURED)
       ##SET1 ACH ACH-BM[]
       ##SET1 DOOR-U 0.2315          $ EXCLUDES OUTSIDE FILM RESISTANCE (BENCHMARK=0.2,
INCLUDING OUTSIDE FILM RESISTANCE 0.68)
       ##SET1 GLASS-U GLASS-U-BM[]   $ BENCHMARK BASED ON LOCATION
       ##SET1 GLASS-SC GLASS-SC-BM[]        $
       ##SET1 GLASS-VT 0.9           $ DOE-2 DEFAULT = 0.9, USED ONLY FOR DAYLIGHTING
CALCULATIONS
       ##SET1 FR-CON 3.037           $ THERMALLY UNBROKEN ALUMINUM, DOE-2 DEFAULT = 0.434
       ##SET1 FR-W 0.125             $ THERMALLY UNBROKEN ALUMINUM
       ##SET1 FR-ABS 0.7             $ DOE-2 DEFAULT = 0.7

##ELSEIF #[MODEL[] EQS PROTOTYPE]
       ##SET1 WALL-ABS 0.3    $ LIGHT COLOR
       ##SET1 WALL-EMT 0.9    $
       ##SET1 WALL-RGH 5      $ SHEET METAL
       ##SET1 ROOF-ABS 0.5    $ MEDIUM
       ##SET1 ROOF-EMT 0.9    $
       ##SET1 ROOF-RGH 4      $ PAINT ON PLYWOOD
       ##SET1 FLOOR-ABS 0.5   $ N/A
       ##SET1 FLOOR-EMT 0.9    $
       ##SET1 FLOOR-RGH 4     $ PLYWOOD
       ##SET1 ACH 0.35         $ MINIMUM VENTILATION RATE = 0.35 ACH (ASHRAE 62.2)
       ##SET1 DOOR-U 0.2315   $ WOOD
       ##SET1 GLASS-CODE1 4901 $ CLEAR/CLEAR, DOUBLE HEAT MIRROR TC88 WITH KRYPTON (NORTH)
       ##SET1 GLASS-CODE2 4902 $ CLEAR/CLEAR, DOUBLE HEAT MIRROR SC75 WITH KRYPTON (EAST, SOUTH,
WEST)
       ##SET1 GLASS-U1 0.078  $ UNSUED WITH GLASS-TYPE CODE
       ##SET1 GLASS-U2 0.088  $
       ##SET1 GLASS-SC1 0.48  $ UNSUED WITH GLASS-TYPE CODE
       ##SET1 GLASS-SC2 0.31  $
       ##SET1 GLASS-VT1 0.519 $ UNSUED WITH GLASS-TYPE CODE
       ##SET1 GLASS-VT2 0.485 $
       ##SET1 FR-CON 0.26     $ FIBERGLASS
       ##SET1 FR-W 0.333      $ FIBERGLASS, 3"
       ##SET1 FR-ABS 0.7      $
##ENDIF

$*******BENCHMARK WINDOW DIMENSIONS FOR 18% WINDOW TO FLOOR AREA RATIO (4-20.65 SQFT
WINDOWS)********
##IF #[MODEL[] EQS BENCHMARK]
       ##SET1 GLASS-W1-BM 3.8278      $ 4.13'X5' WINDOW ON EAST AND ON WEST
       ##SET1 GLASS-HT1-BM 4.6978
       ##SET1 GLASS-X1-BM 2
       ##SET1 GLASS-Y1-BM 0.5
       ##SET1 FRAME-W1-BM 0.1511

       ##SET1 GLASS-W2-BM 10.1046     $ 10.325'X2' WINDOW ON NORTH AND ON SOUTH
       ##SET1 GLASS-HT2-BM 1.7796
       ##SET1 GLASS-X2-BM 13
       ##SET1 GLASS-Y2-BM 0.25
       ##SET1 FRAME-W2-BM 0.1102
##ENDIF

$**************************************

##IF #[MODEL[] EQS BENCHMARK]
       ##SET1 C-EIR #[0.941 * #[3.413 / 9.7]]       $ COOLING-EIR = 0.941*3.413/SEER, BENCHMARK:
SEER9.7 (BARB, p.9)
       ##SET1 H-EIR #[0.582 * #[3.413 / 6.6]]       $ HEATING-EIR = 0.941*3.413/HSPF, BENCHMARK:
6.6HSPF (BARB, p.8)
       ##SET1 DHWEF 0.9036                  $ BARB, p.10
##ELSEIF #[MODEL[] EQS PROTOTYPE]
       ##SET1 C-EIR #[1 / 3.3]                      $ COOLING-EIR = 1/COP47, FSEC-PF=413-04
```

```
       ##SET1 H-EIR #[1 / 3.3]                      $ HEATING-EIR = 1/COP47, FSEC-PF=413-04
       ##SET1 DHWEF 0.93                    $
##ENDIF

$************************BUILDING LOCATION******************************************************
BUILDING-LOCATION
       ALTITUDE = ALT[]
       TIME-ZONE = T-Z[]
       DAYLIGHT-SAVINGS = NO
       HOLIDAY = NO ..

$****************************BENCHMARK MATERIALS**********************************************
##IF #[MODEL[] EQS BENCHMARK]

AL33         = MATERIAL                  $ AIR LAYER, 4" OR MORE, HORIZONTAL ROOFS
              RESISTANCE = 0.92   ..

BR01         = MATERIAL                  $ 3/8" BUILT-UP ROOFING
              THICKNESS    = 0.08313
              CONDUCTIVITY = 0.0939
              DENSITY      = 70
              SPECIFIC-HEAT = 0.35   ..

SC01         = MATERIAL                  $ 1" STUCCO
              THICKNESS    = 0.0833
              CONDUCTIVITY = 0.4167
              DENSITY      = 116
              SPECIFIC-HEAT = 0.2   ..

GP01         = MATERIAL                  $ 1/2" PLASTER BOARD
              THICKNESS    = 0.0417
              CONDUCTIVITY = 0.0926
              DENSITY      = 50
              SPECIFIC-HEAT = 0.2   ..

PW03         = MATERIAL                  $ 1/2" PLYWOOD
              THICKNESS    = 0.0417
              CONDUCTIVITY = 0.0667
              DENSITY      = 34
              SPECIFIC-HEAT = 0.29   ..

WD11         = MATERIAL                   $ 3/4" HARDWOOD
              THICKNESS    = 0.0625
              CONDUCTIVITY = 0.0916
              DENSITY      = 45
              SPECIFIC-HEAT = 0.3   ..

##SET1 W-FF 0.23
##SET1 R-FF 0.11
##SET1 F-FF 0.13

##SET1 WALL-INS-CON  #[WALL-STUD-TH[] / WALL-INS-R[]]
##SET1 ROOF-INS-CON  #[ROOF-STUD-TH[] / ROOF-INS-R[]]
##SET1 FLOOR-INS-CON  #[FLOOR-STUD-TH[] / FLOOR-INS-R[]]

##SET1 INS-DEN  6
##SET1 INS-SH  0.2
##SET1 STUD-CON  0.0667
##SET1 STUD-DEN  2
##SET1 STUD-SH 0.33

##SET1 WALL-FIC-TH WALL-STUD-TH[]
##SET1 WALL-FIC-CON #[#[WALL-INS-CON[] * #[1 - W-FF[]]]
       + #[STUD-CON[] * W-FF[]]]
##SET1 WALL-FIC-DEN #[#[INS-DEN[] * #[1 - W-FF[]]] + #[STUD-DEN[] * W-FF[]]]
##SET1 WALL-FIC-SH #[#[INS-SH[] * #[1 - W-FF[]]] + #[STUD-SH[] * W-FF[]]]

WALL-FIC      = MATERIAL
                      THICKNESS    = WALL-FIC-TH[]
```

```
                      CONDUCTIVITY = WALL-FIC-CON[]
                      DENSITY      = WALL-FIC-DEN[]
                      SPECIFIC-HEAT = WALL-FIC-SH[]  ..

##SET1 ROOF-FIC-TH ROOF-STUD-TH[]
##SET1 ROOF-FIC-CON #[#[ROOF-INS-CON[] * #[1 - R-FF[]]]
       + #[STUD-CON[] * R-FF[]]]
##SET1 ROOF-FIC-DEN #[#[INS-DEN[] * #[1 - R-FF[]]] + #[STUD-DEN[] * R-FF[]]]
##SET1 ROOF-FIC-SH #[#[INS-SH[] * #[1 - R-FF[]]] + #[STUD-SH[] * R-FF[]]]

ROOF-FIC      = MATERIAL
                      THICKNESS    = ROOF-FIC-TH[]
                      CONDUCTIVITY = ROOF-FIC-CON[]
                      DENSITY      = ROOF-FIC-DEN[]
                      SPECIFIC-HEAT = ROOF-FIC-SH[]  ..

##SET1 FLOOR-FIC-TH FLOOR-STUD-TH[]
##SET1 FLOOR-FIC-CON #[#[FLOOR-INS-CON[] * #[1 - F-FF[]]]
       + #[STUD-CON[] * F-FF[]]]
##SET1 FLOOR-FIC-DEN #[#[INS-DEN[] * #[1 - F-FF[]]] + #[STUD-DEN[] * F-FF[]]]
##SET1 FLOOR-FIC-SH #[#[INS-SH[] * #[1 - F-FF[]]] + #[STUD-SH[] * F-FF[]]]

FLOOR-FIC     = MATERIAL
                      THICKNESS    = FLOOR-FIC-TH[]
                      CONDUCTIVITY = FLOOR-FIC-CON[]
                      DENSITY      = FLOOR-FIC-DEN[]
                      SPECIFIC-HEAT = FLOOR-FIC-SH[]  ..

$******************************PROTOTYPE MATERIALS***********************************************
##ELSEIF #[MODEL[] EQS PROTOTYPE]
AS0           = MATERIAL                $ STEEL SIDING (FOR 18 GAUGE SHEET METAL ON BOTH SIDES
OF 1.5" EPS)
               THICKNESS    = 0.0050
               CONDUCTIVITY = 26.0
               DENSITY      = 480
               SPECIFIC-HEAT = 0.1   ..

AF00          = MATERIAL                $ AIR-FILM BELOW FLOOR DECK (ASSUMING 0 MPH WIND SPEED)
               THICKNESS    = 0.0050
               CONDUCTIVITY = 26.0
               DENSITY      = 480
               SPECIFIC-HEAT = 0.1   ..

IN32          = MATERIAL                 $ 3/4" EPS
               THICKNESS    = 0.0625
               CONDUCTIVITY = 0.0200
               DENSITY      = 1.8
               SPECIFIC-HEAT = 0.29   ..

IN35          = MATERIAL                 $ 2" EPS
               THICKNESS    = 0.1667
               CONDUCTIVITY = 0.02
               DENSITY      = 1.8
               SPECIFIC-HEAT = 0.29   ..

IN37          = MATERIAL                 $ 4" EPS
               THICKNESS    = 0.3333
               CONDUCTIVITY = 0.02
               DENSITY      = 1.8
               SPECIFIC-HEAT = 0.29   ..

INSP          = MATERIAL                  $ BIOBASED SPRAY-IN FOAM INSULATION
               RESISTANCE = 7.4105   ..

L-AS          = MATERIAL                  $ Metal Chase (Includes AS01, AL33)
               THICKNESS    = 0.7292
               CONDUCTIVITY = 5.8095
               DENSITY      = 76.97
               SPECIFIC-HEAT = 0.22   ..
```

```
L-IN          = MATERIAL                  $ Metal Encased SIP (Includes AS01, OSB, IN37)
                THICKNESS    = .7292
                CONDUCTIVITY = 4.8967
                DENSITY      = 80.52
                SPECIFIC-HEAT = 0.26   ..

L-SP          = MATERIAL                  $ 11 Gauge 2"x2" Steel Angle Embedded in Spray-in Foam
Insulation
                THICKNESS    = 0.1167
                CONDUCTIVITY = 9.4557
                DENSITY      = 58.34
                SPECIFIC-HEAT = 0.30   ..

OSB           = MATERIAL               $ 3/8" OSB ON BOTH SIDES OF 8" EPS
                RESISTANCE =  0.69  ..

PW03          = MATERIAL                  $ 1/2" PLYWOOD
                THICKNESS    = 0.0417
                CONDUCTIVITY = 0.0667
                DENSITY      = 34
                SPECIFIC-HEAT = 0.29   ..

SIP           = MATERIAL                  $ STRUCTURAL INSULATED PANEL
                THICKNESS    = 0.7083
                CONDUCTIVITY = 0.0209
                DENSITY      = 3.69
                SPECIFIC-HEAT = 0.29   ..

TB22          = MATERIAL                   $ 2"X2" 11 GAUGE SHEET METAL TUBE
                THICKNESS    = 0.1667       $ (PROPERTIES CALCULATED AS WEIGHTED AVERAGE FOR METAL
AND AIR)
                CONDUCTIVITY = 312.9844
                DENSITY      = 108
                SPECIFIC-HEAT = 0.21   ..

TB44          = MATERIAL                   $ 4"X4" 11 GAUGE SHEET METAL TUBE
                THICKNESS    = 0.3333       $ (PROPERTIES CALCULATED AS WEIGHTED AVERAGE FOR METAL
AND AIR)
                CONDUCTIVITY = 312.9844
                DENSITY      = 108
                SPECIFIC-HEAT = 0.21   ..

WD11          = MATERIAL                   $ 3/4" HARDWOOD
                THICKNESS    = 0.0625
                CONDUCTIVITY = 0.0916
                DENSITY      = 45
                SPECIFIC-HEAT = 0.3   ..
##ENDIF
$***************LAYERS
##IF #[MODEL[] EQS BENCHMARK]

WA_1 = LAYERS   MATERIAL = (SC01,PW03,WALL-FIC,GP01)  ..
RF_1 = LAYERS  MATERIAL = (BR01,PW03,AL33,ROOF-FIC,GP01)  ..
FL_1 = LAYERS  MATERIAL = (FLOOR-FIC,PW03,WD11)  ..

##ELSEIF #[MODEL[] EQS PROTOTYPE]

GroWL_1        = LAYERS
                 MATERIAL = (PW03, INSP, PW03, AS01, IN35, AS01)  ..
GroWL_2        = LAYERS
                 MATERIAL = (PW03, TB22, PW03, AS01, IN35, AS01)  ..
CoreWL_1       = LAYERS
                 MATERIAL = (PW03, TB44, IN32, PW03)  ..
CoreWL_2       = LAYERS
                 MATERIAL = (PW03, IN37, PW03)  ..
StudWL_1       = LAYERS
                 MATERIAL = (PW03, INSP, INSP, PW03)  ..
StudWL_2       = LAYERS
```

```
                MATERIAL = (PW03, WD04, PW04)  ..
GroRF_1       = LAYERS
                MATERIAL = (PW03, INSP, PW03, AS01, IN35, AS01)  ..
GroRF_2       = LAYERS
                MATERIAL = (PW03, TB22, PW03, AS01, IN35, AS01)  ..
CoreRF_1      = LAYERS
                MATERIAL = (PW03, L-AS)  ..
CoreRF_2      = LAYERS
                MATERIAL = (PW03, L-IN)  ..
CoreRF_3      = LAYERS
                MATERIAL = (PW03, SIP)  ..
GroFL_1       = LAYERS
                MATERIAL = (AF00, PW03, INSP, INSP, PW03, WD11) ..
GroFL_2       = LAYERS
                MATERIAL = (AF00, PW03, INSP, L-SP, PW03, WD11) ..
CoreFL_1      = LAYERS
                MATERIAL = (AF00, L-AS, PW03, WD11) ..
CoreFL_2      = LAYERS
                MATERIAL = (AF00, L-IN, PW03, WD11) ..
CoreFL_3      = LAYERS
                MATERIAL = (AF00, SIP, PW03, WD11) ..
##ENDIF

$***************CONSTRUCTIONS
##IF #[MODEL[] EQS BENCHMARK]
WALL_1    = CONSTRUCTION
            LAYERS = WA_1
            ABSORPTANCE = WALL-ABS[]
            ROUGHNESS = WALL-RGH[] ..

ROOF_1    = CONSTRUCTION
            LAYERS = RF_1
            ABSORPTANCE = ROOF-ABS[]
            ROUGHNESS = ROOF-RGH[] ..

FLOOR_1   = CONSTRUCTION
            LAYERS = FL_1
            ABSORPTANCE = FLOOR-ABS[]
            ROUGHNESS = FLOOR-RGH[] ..

GroWall_1   = CONSTRUCTION LIKE WALL_1 ..
GroWall_2   = CONSTRUCTION LIKE WALL_1 ..
CoreWall_1  = CONSTRUCTION LIKE WALL_1 ..
CoreWall_2  = CONSTRUCTION LIKE WALL_1 ..
StudWall_1  = CONSTRUCTION LIKE WALL_1 ..
StudWall_2  = CONSTRUCTION LIKE WALL_1 ..

GroRoof_1   = CONSTRUCTION LIKE ROOF_1 ..
GroRoof_2   = CONSTRUCTION LIKE ROOF_1 ..
CoreRoof_1  = CONSTRUCTION LIKE ROOF_1 ..
CoreRoof_2  = CONSTRUCTION LIKE ROOF_1 ..
CoreRoof_3  = CONSTRUCTION LIKE ROOF_1 ..

GroFloor_1  = CONSTRUCTION LIKE FLOOR_1 ..
GroFloor_2  = CONSTRUCTION LIKE FLOOR_1 ..
CoreFloor_1 = CONSTRUCTION LIKE FLOOR_1 ..
CoreFloor_2 = CONSTRUCTION LIKE FLOOR_1 ..
CoreFloor_3 = CONSTRUCTION LIKE FLOOR_1 ..

DOOR-CON1 = CONSTRUCTION
            U-VALUE = DOOR-U[] ..   $EXCLUDES OUTSIDE FILM RESISTANCE
$*************************************
##ELSEIF #[MODEL[] EQS PROTOTYPE]
GroWall_1     = CONSTRUCTION
                LAYERS = GroWL_1
               ABSORPTANCE = WALL-ABS[]
               ROUGHNESS = WALL-RGH[] ..

GroWall_2     = CONSTRUCTION
```

```
                 LAYERS = GroWL_2
                ABSORPTANCE = WALL-ABS[]
                ROUGHNESS = WALL-RGH[] ..

CoreWall_1     = CONSTRUCTION
                 LAYERS = CoreWL_1
                ABSORPTANCE = WALL-ABS[]
                ROUGHNESS = WALL-RGH[] ..

CoreWall_2     = CONSTRUCTION
                 LAYERS = CoreWL_2
                ABSORPTANCE = WALL-ABS[]
                ROUGHNESS = WALL-RGH[] ..

StudWall_1     = CONSTRUCTION
                 LAYERS = StudWL_1
                ABSORPTANCE = WALL-ABS[]
                ROUGHNESS = WALL-RGH[] ..

StudWall_2     = CONSTRUCTION
                 LAYERS = StudWL_2
                ABSORPTANCE = WALL-ABS[]
                ROUGHNESS = WALL-RGH[] ..

GroRoof_1      = CONSTRUCTION
                 LAYERS = GroRF_1
                ABSORPTANCE = ROOF-ABS[]
                ROUGHNESS = ROOF-RGH[] ..

GroRoof_2      = CONSTRUCTION
                 LAYERS = GroRF_2
                ABSORPTANCE = ROOF-ABS[]
                ROUGHNESS = ROOF-RGH[] ..

CoreRoof_1     = CONSTRUCTION
                 LAYERS = CoreRF_1
                ABSORPTANCE = ROOF-ABS[]
                ROUGHNESS = ROOF-RGH[] ..

CoreRoof_2     = CONSTRUCTION
                 LAYERS = CoreRF_2
                ABSORPTANCE = ROOF-ABS[]
                ROUGHNESS = ROOF-RGH[] ..

CoreRoof_3     = CONSTRUCTION
                 LAYERS = CoreRF_3
                ABSORPTANCE = ROOF-ABS[]
                ROUGHNESS = ROOF-RGH[] ..

GroFloor_1     = CONSTRUCTION
                 LAYERS = GroFL_1
                ABSORPTANCE = FLOOR-ABS[]
                ROUGHNESS = FLOOR-RGH[] ..

GroFloor_2     = CONSTRUCTION
                 LAYERS = GroFL_2
                ABSORPTANCE = FLOOR-ABS[]
                ROUGHNESS = FLOOR-RGH[] ..

CoreFloor_1    = CONSTRUCTION
                 LAYERS = CoreFL_1
                ABSORPTANCE = FLOOR-ABS[]
                ROUGHNESS = FLOOR-RGH[] ..

CoreFloor_2    = CONSTRUCTION
                 LAYERS = CoreFL_2
                ABSORPTANCE = FLOOR-ABS[]
                ROUGHNESS = FLOOR-RGH[] ..
```

```
CoreFloor_3   = CONSTRUCTION
                LAYERS = CoreFL_3
               ABSORPTANCE = FLOOR-ABS[]
               ROUGHNESS = FLOOR-RGH[] ..

DOOR-CON1     = CONSTRUCTION
                U-VALUE = DOOR-U[]  ..
##ENDIF
$**********************GLASS TYPE*****************************************************************
##IF #[MODEL[] EQS BENCHMARK]

W-BM = GLASS-TYPE
          SHADING-COEF = GLASS-SC[]
          GLASS-CONDUCTANCE = GLASS-U[]
          VIS-TRANS = GLASS-VT[]
          FRAME-CONDUCTANCE = FR-CON[]
          FRAME-ABS = FR-ABS[]
          SPACER-TYPE-CODE = 0  ..

##ELSEIF #[MODEL[] EQS PROTOTYPE]
W-1   = GLASS-TYPE
        GLASS-TYPE-CODE = GLASS-CODE1[]
        FRAME-CONDUCTANCE = FR-CON[]
        FRAME-ABS = FR-ABS[]   ..
W-2   = GLASS-TYPE
        GLASS-TYPE-CODE = GLASS-CODE2[]
        FRAME-CONDUCTANCE = FR-CON[]
        FRAME-ABS = FR-ABS[]  ..
##ENDIF
$******************************SCHEDULES*******************************************************
OC-1       = DAY-SCHEDULE
             HOURS = (1,24)
VALUES     = (1,
1,
1,
1,
1,
1,
1,
0.8525,
0.3934,
0.2459,
0.2459,
0.2459,
0.2459,
0.2459,
0.2459,
0.2459,
0.2951,
0.5246,
0.8689,
0.8689,
0.8689,
1,
1,
1) ..
OCCUPY-1   = SCHEDULE
             THRU DEC 31 (ALL) OC-1  ..

INFIL-SCH  = SCHEDULE
             THRU DEC 31 (ALL) (1,24) (1)  ..

EQ-1       = DAY-SCHEDULE
             HOURS = (1,24)
VALUES     = (0.0287,
0.026,
0.0249,
0.0241,
0.0241,
```

```
0.0272,
0.0342,
0.0412,
0.0419,
0.0427,
0.0435,
0.0443,
0.0435,
0.0419,
0.0412,
0.0431,
0.0509,
0.0633,
0.0633,
0.0586,
0.0563,
0.0536,
0.045,
0.0365) ..

EQUIP-1     = SCHEDULE
              THRU DEC 31 (ALL) EQ-1   ..

LT-1        = DAY-SCHEDULE
              HOURS = (1,24)
VALUES      = (00.008,
0.008,
0.008,
0.008,
0.024,
0.05,
0.056,
0.05,
0.022,
0.015,
0.015,
0.015,
0.015,
0.015,
0.015,
0.026,
0.056,
0.078,
0.105,
0.126,
0.128,
0.088,
0.049,
0.02) ..

LIGHT-1     = SCHEDULE
              THRU DEC 31 (ALL) LT-1  ..

##IF #[MODEL[] EQS BENCHMARK]
       CONDUCT-TMIN-SCH = SCHEDULE                      $ DBT THRESHOLD VALUE BELOW WHICH DRAPES
ARE CLOSED
       THRU DEC 31 (ALL) (1,24) (0) ..
       DRAPE-U-SCH   = SCHEDULE                             $ CONDUCTANCE MULTIPLIER WHEN SHADES
ARE CLOSED
       THRU DEC 31 (ALL) (1,24) (1) ..

##ELSEIF #[MODEL[] EQS PROTOTYPE]
       CONDUCT-TMIN-SCH = SCHEDULE                      $ DBT THRESHOLD VALUE BELOW WHICH DRAPES
ARE CLOSED
       THRU DEC 31 (ALL) (1,24) (50) ..
       DRAPE-U-SCH   = SCHEDULE                     $ CONDUCTANCE MULTIPLIER WHEN SHADES ARE
CLOSED
       THRU DEC 31 (ALL) (1,24) (1.5) ..
##ENDIF
```

```
DRAPE-SH-SCH      = SCHEDULE                      $ SHADING COEFFICIENT MULTIPLIER WHEN SHADES
ARE CLOSED
##IF #[LOCATION[] EQS HOUSTON]
                   THRU APR 30 (ALL) (1,24) (0.85)
                   THRU OCT 31 (ALL) (1,24) (0.7)
                   THRU DEC 31 (ALL) (1,24) (0.85) ..
##ELSEIF #[LOCATION[] EQS PHOENIX]
                   THRU APR 30 (ALL) (1,24) (0.85)
                   THRU OCT 31 (ALL) (1,24) (0.7)
                   THRU DEC 31 (ALL) (1,24) (0.85) ..
##ELSEIF #[LOCATION[] EQS STERLING]
                   THRU JUN 30 (ALL) (1,24) (0.85)
                   THRU SEP 30 (ALL) (1,24) (0.7)
                   THRU DEC 31 (ALL) (1,24) (0.85) ..
##ENDIF

DRAPE-REOPEN-PROB = = SCHEDULE
       THRU DEC 31 (ALL) (1,24) (0.5) ..

$**************************GENERAL SPACE DEFINITION**********************************************
ROOM = SPACE-CONDITIONS
       PEOPLE-SCHEDULE      = OCCUPY-1              $ MAX = 1
       NUMBER-OF-PEOPLE     = 2
       PEOPLE-HG-LAT        = 164
       PEOPLE-HG-SENS       = 220                   $ BARB, p.28,29

       LIGHTING-SCHEDULE    = LIGHT-1       $ SUM = 1
       LIGHTING-TYPE        = INCAND
       LIGHTING-KW          = #[LT-KWH/YR[] / 365]
       LIGHT-TO-SPACE             = 1               $ FOR SYSTEM-TYPE = PTAC

       EQUIP-SCHEDULE       = EQUIP-1               $ SUM = 1
       EQUIPMENT-KW         = #[EQ-KWH/YR[] / 365]
       EQUIP-SENSIBLE             = EQ-S[]
       EQUIP-LATENT        = EQ-L[]

       FLOOR-WEIGHT         = 0
       TEMPERATURE          = (73.5)           $ AVERAGE OF 71F AND 76F, BARB, p.28
       FURNITURE-TYPE       = LIGHT            $ BARB, p.30
       FURN-WEIGHT          = #[8 * 0.4]       $ 8 LB/SQFT COVERING 40% OF FLOOR AREA, BARB,
p.30
       INF-SCHEDULE         = INFIL-SCH
       INF-METHOD           = AIR-CHANGE       $ DOE-2 DEFAULT=NONE,OR CRACK, RESIDENTIAL
       AIR-CHANGES/HR       = ACH[]         $ ACH=NORMALIZED LEAKAGE x WEATHER FACTOR
       ZONE-TYPE            = CONDITIONED
       SUNSPACE             = NO   ..

$*******************
##IF #[MODEL[] EQS PROTOTYPE]
G1 = BUILDING-SHADE
       X = -5.5
       Y = -10.75
       Z = 0
       HEIGHT = 8.794
       WIDTH = 10.75
       AZIMUTH = 90
       TILT = 90
       TRANSMITTANCE = 0 ..
G2 = BUILDING-SHADE
       X = -5.5
       Y = 0
       Z = 0
       HEIGHT = 15
       WIDTH = 10.75
       AZIMUTH = 0
       TILT = 90
       TRANSMITTANCE = 0 ..
G3 = BUILDING-SHADE
```

```
        X = -16.25
        Y = -10.75
        Z = 8.794
        HEIGHT = 12.41
        WIDTH = 10.75
        AZIMUTH = 180
        TILT = 30
        TRANSMITTANCE = 0 ..
G4 = BUILDING-SHADE
        X = -16.25
        Y = -10.75
        Z = 8.794
        HEIGHT = 10.75
        WIDTH = 10.75
        AZIMUTH = 180
        TILT = 0
        TRANSMITTANCE = 0 ..
H1 = BUILDING-SHADE
        X = 38.833
        Y = 10.083
        Z = 1.5
        HEIGHT = 6.083
        WIDTH = 2.5
        AZIMUTH = 0
        TILT = 90
        TRANSMITTANCE = 0 ..
H2 = BUILDING-SHADE
        X = 38.833
        Y = 2.875
        Z = 1.5
        HEIGHT = 6.083
        WIDTH = 7.208
        AZIMUTH = 90
        TILT = 90
        TRANSMITTANCE = 0 ..

H3 = BUILDING-SHADE
        X = 38.833
        Y = 2.875
        Z = 7.583
        HEIGHT = 2.795
        WIDTH = 7.208
        AZIMUTH = 90
        TILT = 26.565
        TRANSMITTANCE = 0 ..

PV1 = BUILDING-SHADE
        X = 0
        Y = -2.75
        Z = 1.5
        HEIGHT = 8
        WIDTH = 10
        AZIMUTH = 180
        TILT = 90
        TRANSMITTANCE = 0.5 ..
PV2 = BUILDING-SHADE
        X = 10.417
        Y = -2.75
        Z = 1.5
        HEIGHT = 8
        WIDTH = 10
        AZIMUTH = 180
        TILT = 90
        TRANSMITTANCE = 0.5 ..
PV3 = BUILDING-SHADE
        X = 26.25
        Y = -2.75
        Z = 1.5
        HEIGHT = 8
```

```
        WIDTH = 10
        AZIMUTH = 180
        TILT = 90
        TRANSMITTANCE = 0.5 ..
PV4 = BUILDING-SHADE
        X = 26.625
        Y = 10.083
        Z = 11.5
        HEIGHT = 11.643
        WIDTH = 9.708
        AZIMUTH = 180
        TILT = 30
        TRANSMITTANCE = 0 ..
RS1 = BUILDING-SHADE
        X = 26.625
        Y = 10.083
        Z = 11.5
        HEIGHT = 10.083
        WIDTH = 9.708
        AZIMUTH = 180
        TILT = 0
        TRANSMITTANCE = 0 ..
RS2 = BUILDING-SHADE
        X = 36.333
        Y = 10.083
        Z = 1.5
        HEIGHT = 10
        WIDTH = 10.083
        AZIMUTH = 90
        TILT = 90
        TRANSMITTANCE = 0.5 ..
RS3 = BUILDING-SHADE
        X = 36.333
        Y = 20.176
        Z = 1.5
        HEIGHT = 15.821
        WIDTH = 9.708
        AZIMUTH = 0
        TILT = 90
        TRANSMITTANCE = 0.5 ..
RS4 = BUILDING-SHADE
        X = 26.625
        Y = 10.083
        Z = 1.5
        HEIGHT = 10.083
        WIDTH = 9.708
        AZIMUTH = 180
        TILT = 0
        TRANSMITTANCE = 0 ..
##ENDIF
$************************RM-1 SPACE DETAILS**************************************************
RM-1       = SPACE
             SPACE-CONDITIONS = ROOM
             AREA = 458.86
             X = 0
             Y = 0
             Z = 1.5
             AZIMUTH = 0
             VOLUME = 4294.29   ..

POLY-S01   = POLYGON
             (0,0,0)
             (0.188,0,0)
             (0.188,0,7.333)
             (0,0,7.333) ..
S01        = EXTERIOR-WALL
             POLYGON = POLY-S01
             CONSTRUCTION = CoreWall_1 ..
```

```
POLY-S02   = POLYGON
             (0.375,0,0)
             (0.375,-2.15,0)
             (0.375,-2.15,6.258)
             (0.375,0,7.333) ..
S02        = EXTERIOR-WALL
             POLYGON = POLY-S02
             CONSTRUCTION = GroWall_1 ..

POLY-S03   = POLYGON
             (0.375,-2.5,0)
             (8.401,-2.5,0)
             (8.401,-2.5,6.083)
             (0.375,-2.5,6.083) ..
S03        = EXTERIOR-WALL
             POLYGON = POLY-S03
             CONSTRUCTION = GroWall_1 ..
##IF #[MODEL[] EQS PROTOTYPE]
SW03       = WINDOW
             WIDTH = 5.25
             HEIGHT = 1
             X = 0.25
             Y = 3
             GLASS-TYPE = W-2
             FRAME-WIDTH = 0.25
             SETBACK = 0.0
             SHADING-DIVISIONS = 10  ..
##ENDIF

POLY-S04    = POLYGON
             (9.708,-2.5,0)
             (9.708,-0.17,0)
             (9.708,-0.17,7.158)
             (9.708,-2.5,6.083) ..
S04         = EXTERIOR-WALL
             POLYGON = POLY-S04
             CONSTRUCTION = GroWall_1 ..

POLY-S05   = POLYGON
             (9.708,0,0)
             (10.25,0,0)
             (10.25,0,7.333)
             (9.708,0,7.333) ..
S05        = EXTERIOR-WALL
             POLYGON = POLY-S05
             CONSTRUCTION = CoreWall_1 ..

POLY-S06   = POLYGON
             (10.792,0,0)
             (10.792,-2.15,0)
             (10.792,-2.15,6.258)
             (10.792,0,7.333) ..
S06        = EXTERIOR-WALL
             POLYGON = POLY-S06
             CONSTRUCTION = GroWall_1 ..

POLY-S07   = POLYGON
             (10.792,-2.5,0)
             (18.983,-2.5,0)
             (18.983,-2.5,6.083)
             (10.792,-2.5,6.083) ..
S07        = EXTERIOR-WALL
             POLYGON = POLY-S07
             CONSTRUCTION = GroWall_1 ..
##IF #[MODEL[] EQS PROTOTYPE]
SW07       = WINDOW
             WIDTH = 5.25
             HEIGHT = 1
             X = 3.667
```

```
              Y = 3
              GLASS-TYPE = W-2
              FRAME-WIDTH = 0.25
              SETBACK = 0.0
              SHADING-DIVISIONS = 10  ..
##ENDIF

POLY-S08   = POLYGON
              (20.125,-2.5,0)
              (20.125,-0.35,0)
              (20.125,-0.35,7.3158)
              (20.125,-2.5,6.083) ..
S08        = EXTERIOR-WALL
              POLYGON = POLY-S08
              CONSTRUCTION = GroWall_1 ..

POLY-S09   = POLYGON
              (20.125,0,0)
              (25.227,0,0)
              (25.227,0,7.333)
              (20.125,0,7.333) ..
S09        = EXTERIOR-WALL
              POLYGON = POLY-S09
              CONSTRUCTION = CoreWall_1 ..
SD09       = DOOR
              WIDTH = 3
              HEIGHT = 6.667
              CONSTRUCTION = DOOR-CON1
              SETBACK = 0.0
              X = 1.25
              Y = 0
              SHADING-DIVISIONS = 10
              INSIDE-VIS-REFL = 0.5  ..
##IF #[MODEL[] EQS PROTOTYPE]
SW09       = WINDOW
              WIDTH = 0.5
              HEIGHT = 6.667
              X = 4.833
              Y = 0.25
              GLASS-TYPE = W-2
              FRAME-WIDTH = 0.25
              SETBACK = 0.0
              SHADING-DIVISIONS = 10  ..
##ENDIF

POLY-S10   = POLYGON
              (26.625,0,0)
              (26.625,-2.15,0)
              (26.625,-2.15,6.258)
              (26.625,0,7.333) ..
S10        = EXTERIOR-WALL
              POLYGON = POLY-S10
              CONSTRUCTION = GroWall_1 ..

POLY-S11   = POLYGON
              (26.625,-2.5,0)
              (34.651,-2.5,0)
              (34.651,-2.5,6.083)
              (26.625,-2.5,6.083) ..
S11        = EXTERIOR-WALL
              POLYGON = POLY-S11
              CONSTRUCTION = GroWall_1 ..

POLY-S12   = POLYGON
              (35.958,-2.5,0)
              (35.958,-0.35,0)
              (35.958,-0.35,7.158)
              (35.958,-2.5,6.083) ..
S12        = EXTERIOR-WALL
```

```
              POLYGON = POLY-S12
              CONSTRUCTION = GroWall_1 ..

POLY-S13    = POLYGON
              (35.958,0,0)
              (36.146,0,0)
              (36.146,0,7.333)
              (35.958,0,7.333) ..
S13         = EXTERIOR-WALL
              POLYGON = POLY-S13
              CONSTRUCTION = CoreWall_1 ..

POLY-E14    = POLYGON
              (36.333,0,0)
              (36.333,0.313,0)
              (36.333,0.313,7.333)
              (36.333,0,7.333) ..
E14         = EXTERIOR-WALL
              POLYGON = POLY-E14
              CONSTRUCTION = CoreWall_1 ..

POLY-E15    = POLYGON
              (36.333,0.375,0)
              (38.483,0.375,0)
              (38.483,0.375,6.258)
              (36.333,0.375,7.333) ..
E15         = EXTERIOR-WALL
              POLYGON = POLY-E15
              CONSTRUCTION = GroWall_1 ..

POLY-E16    = POLYGON
              (38.833,0.375,0)
              (38.833,2.525,0)
              (38.833,2.525,6.083)
              (38.833,0.375,6.083) ..
E16         = EXTERIOR-WALL
              POLYGON = POLY-E16
              CONSTRUCTION = GroWall_1 ..

POLY-E17    = POLYGON
              (38.833,2.875,0)
              (36.646,2.875,0)
              (36.646,2.875,7.158)
              (38.833,2.875,6.083) ..
E17         = EXTERIOR-WALL
              POLYGON = POLY-E17
              CONSTRUCTION = GroWall_1 ..

POLY-E18    = POLYGON
              (36.333,2.875,0)
              (36.333,9.182,0)
              (36.333,9.182,7.333)
              (36.333,2.875,7.333) ..
E18         = EXTERIOR-WALL
              POLYGON = POLY-E18
              CONSTRUCTION = StudWall_1 ..
##IF #[MODEL[] EQS BENCHMARK]
EW18        = WINDOW
              WIDTH = GLASS-W1-BM[]
              HEIGHT = GLASS-HT1-BM[]
              X = GLASS-X1-BM[]
              Y = GLASS-Y1-BM[]
              GLASS-TYPE = W-BM
              FRAME-WIDTH = FRAME-W1-BM[]
              SETBACK = 0.0
              SHADING-DIVISIONS = 10  ..
##ENDIF

POLY-N19    = POLYGON
```

```
             (36.333,10.083,0)
             (33.366,10.083,0)
             (33.366,10.083,7.333)
             (36.333,10.083,7.333) ..
N19        = EXTERIOR-WALL
             POLYGON = POLY-N19
             CONSTRUCTION = CoreWall_1 ..
##IF #[MODEL[] EQS PROTOTYPE]
ND19       = DOOR
             WIDTH = 2.5
             HEIGHT = 6.667
             CONSTRUCTION = DOOR-CON1
             SETBACK = 0.0
             X = 0.375
             Y = 0
             SHADING-DIVISIONS = 10
             INSIDE-VIS-REFL = 0.5  ..
##ENDIF

POLY-N20   = POLYGON
             (33.125,10.083,0)
             (33.125,12.233,0)
             (33.125,12.233,7.333)
             (33.125,10.083,7.333) ..
N20        = EXTERIOR-WALL
             POLYGON = POLY-N20
             CONSTRUCTION = GroWall_1 ..

POLY-N21   = POLYGON
             (33.125,12.583,0)
             (27.535,12.583,0)
             (27.535,12.583,7.333)
             (33.125,12.583,7.333) ..
N21        = EXTERIOR-WALL
             POLYGON = POLY-N21
             CONSTRUCTION = GroWall_1 ..

POLY-N22   = POLYGON
             (26.625,12.583,0)
             (26.625,10.433,0)
             (26.625,10.433,7.333)
             (26.625,12.583,7.333) ..
N22        = EXTERIOR-WALL
             POLYGON = POLY-N22
             CONSTRUCTION = GroWall_1 ..

POLY-N23   = POLYGON
             (26.625,10.083,0)
             (0.65,10.083,0)
             (0.65,10.083,7.333)
             (26.625,10.083,7.333) ..
N23        = EXTERIOR-WALL
             POLYGON = POLY-N23
             CONSTRUCTION = CoreWall_1 ..
ND23       = DOOR
             WIDTH = 3
             HEIGHT = 6.667
             CONSTRUCTION = DOOR-CON1
             SETBACK = 0.0
             X = 2.25
             Y = 0
             SHADING-DIVISIONS = 10
             INSIDE-VIS-REFL = 0.5  ..
##IF #[MODEL[] EQS PROTOTYPE]
NW23A      = WINDOW
             WIDTH = 0.5
             HEIGHT = 6.667
             X = 1.167
             Y = 0.25
```

```
              GLASS-TYPE = W-2
              FRAME-WIDTH = 0.25
              SETBACK = 0.0
              SHADING-DIVISIONS = 10  ..
NW23B       = WINDOW
              WIDTH = 9.167
              HEIGHT = 6.667
              X = 6.583
              Y = 0.25
              GLASS-TYPE = W-2
              FRAME-WIDTH = 0.25
              SETBACK = 0.0
              SHADING-DIVISIONS = 10  ..
NW23C       = WINDOW
              WIDTH = 9.167
              HEIGHT = 6.667
              X = 17
              Y = 0.25
              GLASS-TYPE = W-2
              FRAME-WIDTH = 0.25
              SETBACK = 0.0
              CONDUCT-TMIN-SCHEDULE = CONDUCT-TMIN-SCH
             CONDUCT-SCHEDULE = DRAPE-U-SCH
             SHADING-SCHEDULE = DRAPE-SH-SCH
              SHADING-DIVISIONS = 10  ..
##ENDIF

POLY-W24    = POLYGON
              (0,10.083,0)
              (0,0.318,0)
              (0,0.318,7.333)
              (0,10.083,7.333) ..
W24         = EXTERIOR-WALL
              POLYGON = POLY-W24
              CONSTRUCTION = CoreWall_1 ..
WW24        = WINDOW
##IF #[MODEL[] EQS PROTOTYPE]
              WIDTH = 9.167
              HEIGHT = 6.667
              X = 0.458
              Y = 0.25
              GLASS-TYPE = W-2
              FRAME-WIDTH = 0.25
              SETBACK = 0.0
              CONDUCT-TMIN-SCHEDULE = CONDUCT-TMIN-SCH
             CONDUCT-SCHEDULE = DRAPE-U-SCH
             SHADING-SCHEDULE = DRAPE-SH-SCH
              SHADING-DIVISIONS = 10  ..

##ELSEIF #[MODEL[] EQS BENCHMARK]
              WIDTH = GLASS-W1-BM[]
              HEIGHT = GLASS-HT1-BM[]
              X = GLASS-X1-BM[]
              Y = GLASS-Y1-BM[]
              GLASS-TYPE = W-BM
              FRAME-WIDTH = FRAME-W1-BM[]
              SETBACK = 0.0
              SHADING-DIVISIONS = 10  ..
##ENDIF

POLY-S25    = POLYGON
              (0,0,7.333)
              (28.687,0,7.333)
              (28.687,0,10)
              (0,0,10) ..
S25         = EXTERIOR-WALL
              POLYGON = POLY-S25
              CONSTRUCTION = CoreWall_1 ..
##IF #[MODEL[] EQS PROTOTYPE]
```

```
SW25A       = WINDOW
              WIDTH = 9.167
              HEIGHT = 1.667
              X = 0.458
              Y = 0.25
              GLASS-TYPE = W-2
              FRAME-WIDTH = 0.25
              SETBACK = 0.0
              OVERHANG-A = 0
              OVERHANG-B = 0.167
              OVERHANG-W = 9.167
              OVERHANG-D = 2.75
              OVERHANG-ANGLE = 0
              CONDUCT-TMIN-SCHEDULE = CONDUCT-TMIN-SCH
             CONDUCT-SCHEDULE = DRAPE-U-SCH
             SHADING-SCHEDULE = DRAPE-SH-SCH
              SHADING-DIVISIONS = 10  ..
SW25B       = WINDOW
              WIDTH = 9.167
              HEIGHT = 1.667
              X = 10.875
              Y = 0.25
              GLASS-TYPE = W-2
              FRAME-WIDTH = 0.25
              SETBACK = 0.0
              OVERHANG-A = 0
              OVERHANG-B = 0.167
              OVERHANG-W = 9.167
              OVERHANG-D = 2.75
              OVERHANG-ANGLE = 0
              CONDUCT-TMIN-SCHEDULE = CONDUCT-TMIN-SCH
             CONDUCT-SCHEDULE = DRAPE-U-SCH
             SHADING-SCHEDULE = DRAPE-SH-SCH
              SHADING-DIVISIONS = 10  ..
SW25C       = WINDOW
              WIDTH = 4.167
              HEIGHT = 1.667
              X = 21.292
              Y = 0.25
              GLASS-TYPE = W-2
              FRAME-WIDTH = 0.25
              SETBACK = 0.0
              OVERHANG-A = 0
              OVERHANG-B = 0.167
              OVERHANG-W = 4.167
              OVERHANG-D = 2.75
              OVERHANG-ANGLE = 0
              CONDUCT-TMIN-SCHEDULE = CONDUCT-TMIN-SCH
             CONDUCT-SCHEDULE = DRAPE-U-SCH
             SHADING-SCHEDULE = DRAPE-SH-SCH
              SHADING-DIVISIONS = 10  ..
SW25D       = WINDOW
              WIDTH = 9.167
              HEIGHT = 1.667
              X = 26.708
              Y = 0.25
              GLASS-TYPE = W-2
              FRAME-WIDTH = 0.25
              SETBACK = 0.0
              OVERHANG-A = 0
              OVERHANG-B = 0.167
              OVERHANG-W = 9.167
              OVERHANG-D = 2.75
              OVERHANG-ANGLE = 0
              CONDUCT-TMIN-SCHEDULE = CONDUCT-TMIN-SCH
             CONDUCT-SCHEDULE = DRAPE-U-SCH
             SHADING-SCHEDULE = DRAPE-SH-SCH
              SHADING-DIVISIONS = 10  ..
```

```
##ELSEIF #[MODEL[] EQS BENCHMARK]
SW25       = WINDOW
             WIDTH = GLASS-W2-BM[]
             HEIGHT = GLASS-HT2-BM[]
             X = GLASS-X2-BM[]
             Y = GLASS-Y2-BM[]
             GLASS-TYPE = W-BM
             FRAME-WIDTH = FRAME-W2-BM[]
             SETBACK = 0.0
             SHADING-DIVISIONS = 10  ..
##ENDIF

POLY-E26   = POLYGON
             (36.333,0,7.333)
             (36.333,8.062,7.333)
             (36.333,8.062,10)
             (36.333,0,10) ..
E26        = EXTERIOR-WALL
             POLYGON = POLY-E26
             CONSTRUCTION = CoreWall_1 ..
##IF #[MODEL[] EQS PROTOTYPE]
EW26       = WINDOW
             WIDTH = 9.167
             HEIGHT = 1.667
             X = 0.458
             Y = 0.25
             GLASS-TYPE = W-2
             FRAME-WIDTH = 0.25
             SETBACK = 0.0
             CONDUCT-TMIN-SCHEDULE = CONDUCT-TMIN-SCH
            CONDUCT-SCHEDULE = DRAPE-U-SCH
            SHADING-SCHEDULE = DRAPE-SH-SCH
             SHADING-DIVISIONS = 10  ..
##ENDIF

POLY-N27   = POLYGON
             (36.333,10.083,7.333)
             (7.646,10.083,7.333)
             (7.646,10.083,10)
             (36.333,10.083,10) ..
N27        = EXTERIOR-WALL
             POLYGON = POLY-N27
             CONSTRUCTION = CoreWall_1 ..
##IF #[MODEL[] EQS PROTOTYPE]
NW27A      = WINDOW
             WIDTH = 9.167
             HEIGHT = 1.667
             X = 0.458
             Y = 0.25
             GLASS-TYPE = W-2
             FRAME-WIDTH = 0.25
             SETBACK = 0.0
             CONDUCT-TMIN-SCHEDULE = CONDUCT-TMIN-SCH
            CONDUCT-SCHEDULE = DRAPE-U-SCH
            SHADING-SCHEDULE = DRAPE-SH-SCH
             SHADING-DIVISIONS = 10  ..
NW27B      = WINDOW
             WIDTH = 4.167
             HEIGHT = 1.667
             X = 10.875
             Y = 0.25
             GLASS-TYPE = W-2
             FRAME-WIDTH = 0.25
             SETBACK = 0.0
             CONDUCT-TMIN-SCHEDULE = CONDUCT-TMIN-SCH
            CONDUCT-SCHEDULE = DRAPE-U-SCH
            SHADING-SCHEDULE = DRAPE-SH-SCH
             SHADING-DIVISIONS = 10  ..
NW27C      = WINDOW
```

```
             WIDTH = 9.167
             HEIGHT = 1.667
             X = 16.292
             Y = 0.25
             GLASS-TYPE = W-2
             FRAME-WIDTH = 0.25
             SETBACK = 0.0
             CONDUCT-TMIN-SCHEDULE = CONDUCT-TMIN-SCH
            CONDUCT-SCHEDULE = DRAPE-U-SCH
            SHADING-SCHEDULE = DRAPE-SH-SCH
             SHADING-DIVISIONS = 10  ..
NW27D      = WINDOW
             WIDTH = 9.167
             HEIGHT = 1.667
             X = 26.708
             Y = 0.25
             GLASS-TYPE = W-2
             FRAME-WIDTH = 0.25
             SETBACK = 0.0
             CONDUCT-TMIN-SCHEDULE = CONDUCT-TMIN-SCH
            CONDUCT-SCHEDULE = DRAPE-U-SCH
            SHADING-SCHEDULE = DRAPE-SH-SCH
             SHADING-DIVISIONS = 10  ..

##ELSEIF #[MODEL[] EQS BENCHMARK]
NW27       = WINDOW
             WIDTH = GLASS-W2-BM[]
             HEIGHT = GLASS-HT2-BM[]
             X = GLASS-X2-BM[]
             Y = GLASS-Y2-BM[]
             GLASS-TYPE = W-BM
             FRAME-WIDTH = FRAME-W2-BM[]
             SETBACK = 0.0
             SHADING-DIVISIONS = 10  ..
##ENDIF

POLY-W28   = POLYGON
             (0,10.083,7.333)
             (0,2.021,7.333)
             (0,2.021,10)
             (0,10.083,10) ..
W28        = EXTERIOR-WALL
             POLYGON = POLY-W28
             CONSTRUCTION = CoreWall_1 ..
##IF #[MODEL[] EQS PROTOTYPE]
WW28       = WINDOW
             WIDTH = 9.167
             HEIGHT = 1.667
             X = 0.458
             Y = 0.25
             GLASS-TYPE = W-2
             FRAME-WIDTH = 0.25
             SETBACK = 0.0
             CONDUCT-TMIN-SCHEDULE = CONDUCT-TMIN-SCH
            CONDUCT-SCHEDULE = DRAPE-U-SCH
            SHADING-SCHEDULE = DRAPE-SH-SCH
             SHADING-DIVISIONS = 10  ..
##ENDIF

$*****************
POLY-S01b   = POLYGON
             (0.188,0,0)
             (0.375,0,0)
             (0.375,0,7.333)
             (0.188,0,7.333) ..
S01b        = EXTERIOR-WALL
             POLYGON = POLY-S01b
             CONSTRUCTION = CoreWall_2 ..
```

```
POLY-S02b   = POLYGON
             (0.375,-2.15,0)
             (0.375,-2.5,0)
             (0.375,-2.5,6.083)
             (0.375,-2.15,6.258) ..
S02b        = EXTERIOR-WALL
             POLYGON = POLY-S02b
             CONSTRUCTION = GroWall_2 ..

POLY-S03b   = POLYGON
             (8.401,-2.5,0)
             (9.708,-2.5,0)
             (9.708,-2.5,6.083)
             (8.401,-2.5,6.083) ..
S03b        = EXTERIOR-WALL
             POLYGON = POLY-S03b
             CONSTRUCTION = GroWall_2 ..

POLY-S04b    = POLYGON
             (9.708,-0.17,0)
             (9.708,0,0)
             (9.708,0,7.333)
             (9.708,-0.17,7.158) ..
S04b         = EXTERIOR-WALL
             POLYGON = POLY-S04b
             CONSTRUCTION = GroWall_2 ..

POLY-S05b   = POLYGON
             (10.25,0,0)
             (10.792,0,0)
             (10.792,0,7.333)
             (10.25,0,7.333) ..
S05b        = EXTERIOR-WALL
             POLYGON = POLY-S05b
             CONSTRUCTION = CoreWall_2 ..

POLY-S06b   = POLYGON
             (10.792,-2.15,0)
             (10.792,-2.5,0)
             (10.792,-2.5,6.083)
             (10.792,-2.15,6.258) ..
S06b        = EXTERIOR-WALL
             POLYGON = POLY-S06b
             CONSTRUCTION = GroWall_2 ..

POLY-S07b   = POLYGON
             (18.983,-2.5,0)
             (20.125,-2.5,0)
             (20.125,-2.5,6.083)
             (18.983,-2.5,6.083) ..
S07b        = EXTERIOR-WALL
             POLYGON = POLY-S07b
             CONSTRUCTION = GroWall_2 ..

POLY-S08b   = POLYGON
             (20.125,-0.35,0)
             (20.125,0,0)
             (20.125,0,7.333)
             (20.125,-0.35,7.158) ..
S08b        = EXTERIOR-WALL
             POLYGON = POLY-S08b
             CONSTRUCTION = GroWall_2 ..

POLY-S09b   = POLYGON
             (25.227,0,0)
             (26.625,0,0)
             (26.625,0,7.333)
             (25.227,0,7.333) ..
S09b        = EXTERIOR-WALL
```

```
               POLYGON = POLY-S09b
               CONSTRUCTION = CoreWall_2 ..

POLY-S10b    = POLYGON
               (26.625,-2.15,0)
               (26.625,-2.5,0)
               (26.625,-2.5,6.083)
               (26.625,-2.15,6.258) ..
S10b         = EXTERIOR-WALL
               POLYGON = POLY-S10b
               CONSTRUCTION = GroWall_2 ..

POLY-S11b    = POLYGON
               (34.651,-2.5,0)
               (35.958,-2.5,0)
               (35.958,-2.5,6.083)
               (34.651,-2.5,6.083) ..
S11b         = EXTERIOR-WALL
               POLYGON = POLY-S11b
               CONSTRUCTION = GroWall_2 ..

POLY-S12b    = POLYGON
               (35.958,-0.35,0)
               (35.958,0,0)
               (35.958,0,7.333)
               (35.958,-0.35,7.158) ..
S12b         = EXTERIOR-WALL
               POLYGON = POLY-S12b
               CONSTRUCTION = GroWall_2 ..

POLY-S13b    = POLYGON
               (36.146,0,0)
               (36.333,0,0)
               (36.333,0,7.333)
               (36.146,0,7.333) ..
S13b         = EXTERIOR-WALL
               POLYGON = POLY-S13b
               CONSTRUCTION = CoreWall_2 ..

POLY-E14b    = POLYGON
               (36.333,0.313,0)
               (36.333,0.375,0)
               (36.333,0.375,7.333)
               (36.333,0.313,7.333) ..
E14b         = EXTERIOR-WALL
               POLYGON = POLY-E14b
               CONSTRUCTION = CoreWall_2 ..

POLY-E15b    = POLYGON
               (38.483,0.375,0)
               (38.833,0.375,0)
               (38.833,0.375,6.083)
               (38.483,0.375,6.258) ..
E15b         = EXTERIOR-WALL
               POLYGON = POLY-E15b
               CONSTRUCTION = GroWall_2 ..

POLY-E16b    = POLYGON
               (38.833,2.525,0)
               (38.833,2.875,0)
               (38.833,2.875,6.083)
               (38.833,2.5255,6.083) ..
E16b         = EXTERIOR-WALL
               POLYGON = POLY-E16b
               CONSTRUCTION = GroWall_2 ..

POLY-E17b    = POLYGON
               (36.646,2.875,0)
               (36.333,2.875,0)
```

```
               (36.333,2.875,7.333)
               (36.646,2.875,7.158) ..
E17b          = EXTERIOR-WALL
               POLYGON = POLY-E17b
               CONSTRUCTION = GroWall_2 ..

POLY-E18b     = POLYGON
               (36.333,9.182,0)
               (36.333,10.083,0)
               (36.333,10.083,7.333)
               (36.333,9.182,7.333) ..
E18b          = EXTERIOR-WALL
               POLYGON = POLY-E18b
               CONSTRUCTION = StudWall_2 ..

POLY-N19b     = POLYGON
               (33.366,10.083,0)
               (33.125,10.083,0)
               (33.125,10.083,7.333)
               (33.366,10.083,7.333) ..
N19b          = EXTERIOR-WALL
               POLYGON = POLY-N19b
               CONSTRUCTION = CoreWall_2 ..

POLY-N20b     = POLYGON
               (33.125,12.233,0)
               (33.125,12.583,0)
               (33.125,12.583,7.333)
               (33.125,12.233,7.333) ..
N20b          = EXTERIOR-WALL
               POLYGON = POLY-N20b
               CONSTRUCTION = GroWall_2 ..

POLY-N21b     = POLYGON
               (27.535,12.583,0)
               (26.625,12.583,0)
               (26.625,12.583,7.333)
               (27.535,12.583,7.333) ..
N21b          = EXTERIOR-WALL
               POLYGON = POLY-N21b
               CONSTRUCTION = GroWall_2 ..

POLY-N22b     = POLYGON
               (26.625,10.433,0)
               (26.625,10.083,0)
               (26.625,10.083,7.333)
               (26.625,10.433,7.333) ..
N22b          = EXTERIOR-WALL
               POLYGON = POLY-N22b
               CONSTRUCTION = GroWall_2 ..

POLY-N23b     = POLYGON
               (0.65,10.083,0)
               (0,10.083,0)
               (0,10.083,7.333)
               (0.65,10.083,7.333) ..
N23b          = EXTERIOR-WALL
               POLYGON = POLY-N23b
               CONSTRUCTION = CoreWall_2 ..

POLY-W24b     = POLYGON
               (0,0.318,0)
               (0,0,0)
               (0,0,7.333)
               (0,0.318,7.333) ..
W24b          = EXTERIOR-WALL
               POLYGON = POLY-W24b
               CONSTRUCTION = CoreWall_2 ..
```

```
POLY-S25b   = POLYGON
             (28.687,0,7.333)
             (36.333,0,7.333)
             (36.333,0,10)
             (28.687,0,10) ..
S25b        = EXTERIOR-WALL
             POLYGON = POLY-S25b
             CONSTRUCTION = CoreWall_2 ..

POLY-E26b   = POLYGON
             (36.333,8.062,7.333)
             (36.333,10.083,7.333)
             (36.333,10.083,10)
             (36.333,8.062,10) ..
E26b        = EXTERIOR-WALL
             POLYGON = POLY-E26b
             CONSTRUCTION = CoreWall_2 ..

POLY-N27b   = POLYGON
             (7.646,10.083,7.333)
             (0,10.083,7.333)
             (0,10.083,10)
             (7.646,10.083,10) ..
N27b        = EXTERIOR-WALL
             POLYGON = POLY-N27b
             CONSTRUCTION = CoreWall_2 ..

POLY-W28b   = POLYGON
             (0,2.021,7.333)
             (0,0,7.333)
             (0,0,10)
             (0,2.021,10) ..
W28b        = EXTERIOR-WALL
             POLYGON = POLY-W28b
             CONSTRUCTION = CoreWall_2 ..

$*******************
POLY-R01   = POLYGON
             (0,0,10)
             (32.833,0,10)
             (32.833,10.083,10)
             (0,10.083,10) ..
R01        = ROOF
             POLYGON = POLY-R01
             CONSTRUCTION = CoreRoof_1  ..

POLY-R02   = POLYGON
             (0.375,-2.5,6.083)
             (8,-2.5,6.083)
             (8,0,7.333)
             (0.375,0,7.333) ..
R02        = ROOF
             POLYGON = POLY-R02
             CONSTRUCTION = GroRoof_1  ..

POLY-R03   = POLYGON
             (10.792,-2.5,6.083)
             (18.792,-2.5,6.083)
             (18.792,0,7.333)
             (10.792,0,7.333) ..
R03        = ROOF
             POLYGON = POLY-R03
             CONSTRUCTION = GroRoof_1  ..

POLY-R04   = POLYGON
             (26.625,-2.5,6.083)
             (34.625,-2.5,6.083)
             (34.625,0,7.333)
             (26.625,0,7.333) ..
```

```
R04        = ROOF
             POLYGON = POLY-R04
             CONSTRUCTION = GroRoof_1  ..

POLY-R05   = POLYGON
             (38.833,0.375,6.083)
             (38.833,2.542,6.083)
             (36.333,2.542,7.333)
             (36.333,0.375,7.333) ..
R05        = ROOF
             POLYGON = POLY-R05
             CONSTRUCTION = GroRoof_1  ..

POLY-R06   = POLYGON
             (33.125,12.583,7.333)
             (28.125,12.583,7.333)
             (28.125,10.083,7.333)
             (33.125,10.083,7.333)  ..
R06        = ROOF
             POLYGON = POLY-R06
             CONSTRUCTION = GroRoof_1  ..

POLY-F01   = POLYGON
             (0,0,0)
             (0,10.083,0)
             (32.833,10.083,0)
             (32.833,0,0) ..
F01        = EXTERIOR-WALL
             POLYGON = POLY-F01
             CONSTRUCTION = CoreFloor_1  ..

POLY-F02   = POLYGON
             (0.375,0,0)
             (8.375,0,0)
             (8.375,-2.5,0)
             (0.375,-2.5,0)..
F02        = EXTERIOR-WALL
             POLYGON = POLY-F02
             CONSTRUCTION = GroFloor_1  ..

POLY-F03   = POLYGON
             (10.792,0,0)
             (18.792,0,0)
             (18.792,-2.5,0)
             (10.792,-2.5,0) ..
F03        = EXTERIOR-WALL
             POLYGON = POLY-F03
             CONSTRUCTION = GroFloor_1  ..

POLY-F04   = POLYGON
             (26.625,-2.5,0)
             (26.625,0,0)
             (34.625,0,0)
             (34.625,-2.5,0) ..
F04        = EXTERIOR-WALL
             POLYGON = POLY-F04
             CONSTRUCTION = GroFloor_1  ..

POLY-F05   = POLYGON
             (38.833,0.375,0)
             (36.333,0.375,0)
             (36.333,2.542,0)
             (38.833,2.542,0) ..
F05        = EXTERIOR-WALL
             POLYGON = POLY-F05
             CONSTRUCTION = GroFloor_1  ..

POLY-F06   = POLYGON
             (33.125,10.083,0)
```

```
              (28.125,10.083,0)
              (28.125,12.583,0)
              (33.125,12.583,0)  ..
F06        = EXTERIOR-WALL
              POLYGON = POLY-F06
              CONSTRUCTION = GroFloor_1  ..

$*****************
POLY-R01b   = POLYGON
              (32.833,0,10)
              (35.458,0,10)
              (35.458,10.083,10)
              (32.833,10.083,10) ..
R01b        = ROOF
              POLYGON = POLY-R01b
              CONSTRUCTION = CoreRoof_2  ..

POLY-R01c   = POLYGON
              (35.458,0,10)
              (36.333,0,10)
              (36.333,10.083,10)
              (35.458,10.083,10) ..
R01c        = ROOF
              POLYGON = POLY-R01c
              CONSTRUCTION = CoreRoof_3  ..

POLY-R02b   = POLYGON
              (8,-2.5,6.083)
              (9.708,-2.5,6.083)
              (9.708,0,7.333)
              (8,0,7.333) ..
R02b        = ROOF
              POLYGON = POLY-R02b
              CONSTRUCTION = GroRoof_2  ..

POLY-R03b   = POLYGON
              (18.792,-2.5,6.083)
              (20.125,-2.5,6.083)
              (20.125,0,7.333)
              (18.792,0,7.333) ..
R03b        = ROOF
              POLYGON = POLY-R03b
              CONSTRUCTION = GroRoof_2  ..

POLY-R04b   = POLYGON
              (34.625,-2.5,6.083)
              (35.958,-2.5,6.083)
              (35.958,0,7.333)
              (34.625,0,7.333) ..
R04b        = ROOF
              POLYGON = POLY-R04b
              CONSTRUCTION = GroRoof_2  ..

POLY-R05b   = POLYGON
              (38.833,2.542,6.083)
              (38.833,2.875,6.083)
              (36.333,2.875,7.333)
              (36.333,2.542,7.333) ..
R05b        = ROOF
              POLYGON = POLY-R05b
              CONSTRUCTION = GroRoof_2  ..

POLY-R06b   = POLYGON
              (28.125,10.083,7.333)
              (28.125,12.583,7.333)
              (26.625,12.583,7.333)
              (26.625,10.083,7.333)  ..
R06b        = ROOF
              POLYGON = POLY-R06b
```

```
               CONSTRUCTION = GroRoof_2  ..

POLY-F01b    = POLYGON
               (32.833,0,0)
               (32.833,10.083,0)
               (35.458,10.083,0)
               (35.458,0,0) ..
F01b         = EXTERIOR-WALL
               POLYGON = POLY-F01b
               CONSTRUCTION = CoreFloor_2  ..

POLY-F01c    = POLYGON
               (35.458,0,0)
               (35.458,10.083,0)
               (36.333,10.083,0)
               (36.333,0,0) ..
F01c         = EXTERIOR-WALL
               POLYGON = POLY-F01c
               CONSTRUCTION = CoreFloor_2  ..

POLY-F02b    = POLYGON
               (8.375,0,0)
               (9.708,0,0)
               (9.708,-2.5,0)
               (8.375,-2.5,0)..
F02b         = EXTERIOR-WALL
               POLYGON = POLY-F02b
               CONSTRUCTION = GroFloor_2  ..

POLY-F03b    = POLYGON
               (18.792,0,0)
               (20.125,0,0)
               (20.125,-2.5,0)
               (18.792,-2.5,0) ..
F03b        = EXTERIOR-WALL
               POLYGON = POLY-F03b
               CONSTRUCTION = GroFloor_2  ..

POLY-F04b    = POLYGON
               (34.625,0,0)
               (35.958,0,0)
               (35.958,-2.5,0)
               (34.625,-2.5,0) ..
F04b         = EXTERIOR-WALL
               POLYGON = POLY-F04b
               CONSTRUCTION = GroFloor_2  ..

POLY-F05b    = POLYGON
               (36.333,2.542,0)
               (36.333,2.875,0)
               (38.833,2.875,0)
               (38.833,2.542,0) ..
F05b         = EXTERIOR-WALL
               POLYGON = POLY-F05b
               CONSTRUCTION = GroFloor_2  ..

POLY-F06b    = POLYGON
               (28.125,10.083,0)
               (26.625,10.083,0)
               (26.625,12.583,0)
               (28.125,12.583,0) ..
F06b         = EXTERIOR-WALL
               POLYGON = POLY-F06b
               CONSTRUCTION = GroFloor_2  ..
               ..
$************************
SCH-1       = SCHEDULE
               THRU DEC 31 (ALL)(1,24)(1)
               ..
```

```
OA         = REPORT-BLOCK
             VARIABLE-TYPE=GLOBAL
             VARIABLE-LIST = (3,4,6,10,15,17)    $ OUTSIDE WBT, DBT,CLOUD AMT:0-10,TOTAL
HORZ.SOLAR(BTU/HR-FT^2),
             ..                                  $ HUM.RATIO (LB/LB),WIND SPEED (KNOTS)
REP1            = HOURLY-REPORT
REPORT-SCHEDULE = SCH-1
REPORT-BLOCK    = (OA)
..

END  ..
COMPUTE  LOADS   ..

$***************************SYSTEM***************************************************

INPUT SYSTEMS
       INPUT-UNITS = ENGLISH
       OUTPUT-UNITS = ENGLISH  ..

TITLE   LINE-1 *TAMU SOLAR DECATHLON 2007* ..

SYSTEMS-REPORT
            VERIFICATION = (ALL-VERIFICATION)
            SUMMARY = (ALL-SUMMARY) ..

DHWCURVE   = CURVE-FIT
             TYPE = LINEAR
             COEFFICIENTS = (0,1)  ..

FAN-SCHED  = SCHEDULE
             THRU DEC 31 (ALL) (1,24) (1)  ..

##IF #[LOCATION[] EQS HOUSTON]
HEATON     = SCHEDULE                        $ HEATING SYSTEM OPERATION, BARB, p.30
             THRU APR 30 (ALL) (1,24) (1)
             THRU OCT 31 (ALL) (1,24) (0)       $ COOLING SYSTEM OPERATION, BARB, p.30
             THRU DEC 31 (ALL) (1,24) (1)  ..
COOLON     = SCHEDULE
             THRU MAR 31 (ALL) (1,24) (0)
             THRU NOV 30 (ALL) (1,24) (1)
             THRU DEC 31 (ALL) (1,24) (0)  ..
##ELSEIF #[LOCATION[] EQS PHOENIX]
HEATON     = SCHEDULE
             THRU APR 30 (ALL) (1,24) (1)
             THRU OCT 31 (ALL) (1,24) (0)
             THRU DEC 31 (ALL) (1,24) (1)  ..
COOLON     = SCHEDULE
             THRU MAR 31 (ALL) (1,24) (0)
             THRU NOV 30 (ALL) (1,24) (1)
             THRU DEC 31 (ALL) (1,24) (0)  ..
##ELSEIF #[LOCATION[] EQS STERLING]
HEATON     = SCHEDULE
             THRU JUN 30 (ALL) (1,24) (1)
             THRU SEP 30 (ALL) (1,24) (0)
             THRU DEC 31 (ALL) (1,24) (1)  ..
COOLON     = SCHEDULE
             THRU MAY 31 (ALL) (1,24) (0)
             THRU OCT 31 (ALL) (1,24) (1)
             THRU DEC 31 (ALL) (1,24) (0)  ..
##ENDIF

THEAT      = SCHEDULE
             THRU DEC 31 (ALL) (1,24) (71)  ..    $ THERMOSTAT SETPOINTS, BARB, p.28
TCOOL      = SCHEDULE
             THRU DEC 31 (ALL) (1,24) (76)  ..

DHW-INLET-T-SCH = SCHEDULE                        $ WATER-MAINS TEMPERATURE, BARB, p.14
##IF #[LOCATION[] EQS HOUSTON]
               THRU JAN 31 (ALL) (1,24) (64.4)
```

```
               THRU FEB 28 (ALL) (1,24) (64.7)
               THRU MAR 31 (ALL) (1,24) (67.5)
               THRU APR 30 (ALL) (1,24) (72.0)
               THRU MAY 31 (ALL) (1,24) (77.0)
               THRU JUN 30 (ALL) (1,24) (81.3)
               THRU JUL 31 (ALL) (1,24) (83.7)
               THRU AUG 31 (ALL) (1,24) (83.6)
               THRU SEP 30 (ALL) (1,24) (81.0)
               THRU OCT 31 (ALL) (1,24) (76.6)
               THRU NOV 30 (ALL) (1,24) (71.6)
               THRU DEC 31 (ALL) (1,24) (67.2) ..
##ELSEIF #[LOCATION[] EQS PHOENIX]
               THRU JAN 31 (ALL) (1,24) (65.1)
               THRU FEB 28 (ALL) (1,24) (66.1)
               THRU MAR 31 (ALL) (1,24) (70.3)
               THRU APR 30 (ALL) (1,24) (76.7)
               THRU MAY 31 (ALL) (1,24) (83.5)
               THRU JUN 30 (ALL) (1,24) (89.1)
               THRU JUL 31 (ALL) (1,24) (91.9)
               THRU AUG 31 (ALL) (1,24) (91.2)
               THRU SEP 30 (ALL) (1,24) (87.2)
               THRU OCT 31 (ALL) (1,24) (81.0)
               THRU NOV 30 (ALL) (1,24) (74.1)
               THRU DEC 31 (ALL) (1,24) (68.4) ..
##ELSEIF #[LOCATION[] EQS STERLING]
               THRU JAN 31 (ALL) (1,24) (48.8)
               THRU FEB 28 (ALL) (1,24) (47.6)
               THRU MAR 31 (ALL) (1,24) (49.6)
               THRU APR 30 (ALL) (1,24) (54.2)
               THRU MAY 31 (ALL) (1,24) (60.2)
               THRU JUN 30 (ALL) (1,24) (66.1)
               THRU JUL 31 (ALL) (1,24) (70.2)
               THRU AUG 31 (ALL) (1,24) (71.6)
               THRU SEP 30 (ALL) (1,24) (69.9)
               THRU OCT 31 (ALL) (1,24) (65.5)
               THRU NOV 30 (ALL) (1,24) (59.6)
               THRU DEC 31 (ALL) (1,24) (53.7) ..
##ENDIF

DHW-1       = DAY-SCHEDULE
             HOURS = (1,24)
VALUES     = (0.0062,
0.0031,
0.0008,
0.0008,
0.0031,
0.0218,
0.0748,
0.0794,
0.0763,
0.067,
0.0607,
0.0483,
0.0421,
0.0374,
0.0327,
0.0374,
0.0436,
0.0576,
0.0685,
0.0654,
0.0592,
0.0483,
0.0421,
0.0234) ..

DHWSCH-1    = SCHEDULE
             THRU DEC 31 (ALL) DHW-1  ..
```

```
$*********ZONE DATA********************

ZONE-CON1     = ZONE-CONTROL
               DESIGN-HEAT-T = 71
               DESIGN-COOL-T = 76
               HEAT-TEMP-SCH = THEAT
               COOL-TEMP-SCH = TCOOL
               THERMOSTAT-TYPE = PROPORTIONAL               $ DOE-2 DEFAULT
               THROTTLING-RANGE = 2                 $ DOE-2 DEFAULT
               ..
ZONE-AIR1     = ZONE-AIR
               CFM/SQFT = 1
$              OUTSIDE-AIR-CFM = 70                 THROUGH ERV (UNUSED IN RESYS)
               ..
RM-1  = ZONE
       ZONE-TYPE = CONDITIONED
       ZONE-CONTROL = ZONE-CON1
       ZONE-AIR = ZONE-AIR1
       ZONE-REPORTS = YES
        ..
$*********SYSTEM DATA******************

S-CTRL = SYSTEM-CONTROL
       MAX-SUPPLY-T = 105                   $ DOE-2 DEFAULT
       MIN-SUPPLY-T = 55                    $ DOE-2 DEFAULT
       COOLING-SCHEDULE = COOLON
       HEATING-SCHEDULE = HEATON
       ..

 S-AIR = SYSTEM-AIR
$      SUPPLY-CFM =                    DOE-2 DEFAULT: FROM LOADS OR CAPACITIES
$      RATED-CFM =                     DOE-2 DEFAULT: NO PERFORMANCE ADJUSTMENT
$      NATURAL-VENT-AC =
$      NATURAL-VENT-SCH =
$      VENT-TEMP-SCH =
       DUCT-AIR-LOSS = 0
       DUCT-DELTA-T = 0
       VENT-METHOD =  AIR-CHANGE            $ DOE-2 DEFAULT
       MAX-VENT-RATE = 1             $ 1 ACH/HR = 70 CFM. DOE-2 DEFAULT: 20 ACH/HR
       ..

S-FAN = SYSTEM-FANS
       SUPPLY-STATIC = 0.5                  $ DOE-2 DEFAULT: FROM FROM SUPPLY-DELTA-T AND
SUPPLY-KW
       SUPPLY-EFF = 0.75                    $ (DEFAULT FROM FROM SUPPLY-DELTA-T AND SUPPLY-KW)
TYPICAL VALUES FOR RESIDENCE
       SUPPLY-DELTA-T = 0.396        $ DOE-2 DEFAULT
       SUPPLY-KW = 0.000128          $ (KW/CFM) DOE-2 DEFAULT
        FAN-SCHEDULE = FAN-SCHED     $ ALWAYS ON, DOE-2 DEFAULT ALSO
       FAN-CONTROL = CYCLING         $ DOE-2 DEFAULT
       ..

S-EQUIP = SYSTEM-EQUIPMENT
       COOLING-CAPACITY = 11700      $ DOE-2 DEFAULT: DEPENDS ON PEAK LOADS
       HEATING-CAPACITY = -10900     $ DOE-2 DEFAULT: DEPENDS ON PEAK LOADS
       COOLING-EIR = C-EIR[]
       HEATING-EIR = H-EIR[]
       COOL-SH-CAP = 7839            $ SHR = 0.67, DOE-2 DEFAULT: FROM LOADS
       FURNACE-AUX = 0  ..

SYSTEM-1      = SYSTEM
               SYSTEM-TYPE = RESYS
               ZONE-NAMES = (RM-1)
               SYSTEM-CONTROL = S-CTRL
               SYSTEM-AIR = S-AIR
               SYSTEM-FANS = S-FAN
               SYSTEM-EQUIPMENT = S-EQUIP
               HEAT-SOURCE = HEAT-PUMP
               SIZING-RATIO = 1.0
```

```
                SYSTEM-REPORTS = YES   ..

PLANT-1        = PLANT-ASSIGNMENT
                SYSTEM-NAMES = (SYSTEM-1)
                DHW-TYPE = ELECTRIC
                DHW-SCH = DHWSCH-1
                DHW-SUPPLY-T = 120
                DHW-GAL/MIN  = #[40 / 60]     $ HOT WATER 40 GAL PER DAY/60
                DHW-EIR = #[1 / DHWEF[]]        $ DOE-2 DEFAULT: GAS: 1.39, ELECTRIC:1
                DHW-LOSS = 0                  $
                DHW-EIR-FPLR = DHWCURVE
                PLANT-REPORTS = YES  ..

$**********REPORT-BLOCK FOR OUTSIDE AND ZONE TEMPERATURES, 05/17/2006,M.MALHOTRA *************
SCH-1            = SCHEDULE
                   THRU DEC 31 (ALL)(1,24)(1)  ..
OADBT            = REPORT-BLOCK
                   VARIABLE-TYPE=GLOBAL
                   VARIABLE-LIST = (8)    ..        $ OUTSIDE DRY BULB TEMPERATURE
RM-1T            = REPORT-BLOCK
                   VARIABLE-TYPE=RM-1
                   VARIABLE-LIST = (6)    ..        $ ZONE TEMPERATURE

$**********HOURLY-REPORT FOR OUTSIDE AND ZONE TEMPERATURES, 05/17/2006,M.MALHOTRA *************
REP1             = HOURLY-REPORT
REPORT-SCHEDULE = SCH-1
REPORT-BLOCK = (OADBT,RM-1T) ..
END  ..
COMPUTE SYSTEMS ..

INPUT PLANT
        INPUT-UNITS = ENGLISH
        OUTPUT-UNITS = ENGLISH  ..

TITLE   LINE-1 *TAMU SOLAR DECATHLON 2007* ..

PLANT-REPORT
        VERIFICATION  = (ALL-VERIFICATION)
         SUMMARY       = (ALL-SUMMARY,BEPS,BEPU) ..

PLANT-1 = PLANT-ASSIGNMENT   ..

SCH-1            = SCHEDULE
                   THRU DEC 31 (ALL)(1,24)(1)  ..
END-USE-ELEC     = REPORT-BLOCK
                   VARIABLE-TYPE = END-USE
                   VARIABLE-LIST = (1,3,5,6,8,9,12) .. $ HEATING ELEC,COOLING ELEC,DHW ELEC,
TOTAL-ELEC      = REPORT-BLOCK
                   VARIABLE-TYPE = PLANT
                   VARIABLE-LIST = (10) ..    $ TOTAL ELEC LOAD TO BE MET BY PLANT
REP1             = HOURLY-REPORT
REPORT-SCHEDULE = SCH-1
REPORT-BLOCK     = (END-USE-ELEC,TOTAL-ELEC) ..

END   ..
COMPUTE PLANT   ..
STOP  ..
```

Appendix B - F-CHART and PVF-CHART input and output files

```
Inputs              1  Number of collector panels....  6
For Collector       2  Collector panel area..........  20.2          FT2
                    3  FR*UL (test slope)............  .05           BTU/HR-FT2-F
                    4  FR*TAU*ALPHA (test intercept).  .42
                    5  Collector slope...............  90            DEG
                    6  Collector azimuth (South=0)...  0             DEG
                    7  Receiver orient (1=EW,2=NS)...  2
                    8  Inc angle mod (perpendicular).
                      1   .999   .998   .995   .981   .953   .882
                     .7   .35    0
                    9  Inc angle mod (parallel)......
                      1   .999   .998   .995   .981   .953   .882
                     .7   .35    0
                    10 Collector flowrate/area.......  11            LB/HR-FT2
                    11 Collector fluid specific heat.  1             BTU/LB-F
                    12 Modify test valuessss=Y,2=N)..  2
                    13   Test collector flowrate/area  11            LB/HR-FT2
                    14   Test fluid specific heat....  1             BTU/LB-F

Inputs              1  City call number..............  96
For System          2  Water storage volume..........  500           GALLONS
                    3  Building UA (0 for DHW only)..  305           BTU/HR-F
                    4  Fuel (1=EL,2=NG,3=OIL,4=OTHER)  1
                    5  Efficiency of fuel usage......  100           %
                    6  Domestic hot water (1=Y,2=N)..  1
                    7    Daily hot water usage.......  26            GALLONS
                    8    Water set temperature.......  110           F
                    9    Environment temperature.....  68            F
                    10   DHW storage tank size.......  204           GALLONS
                    11   UA of aux storage tank......  7.6           BTU/HR-F
                    12 Pipe heat loss (1=Y,2=N)......  2
                    13   Inlet pipe UA...............  5             BTU/HR-F
                    14   Outlet pipe UA..............  5             BTU/HR-F
                    15 Relative load HX size.........  1
                    16 Collector-storage HX (1=Y,2=N)  2
                    17   Tank side flowrate/area.....  11            LB/HR-FT2
                    18   Heat exchanger effectiveness  .5

Outputs                   SOLAR   HEAT    DHW    AUX      F
                          MMBTU   MMBTU   MMBTU  MMBTU
                     JAN   3.5     4.1    0.5    3.4    0.27
                     FEB   3.2     4.0    0.5    3.4    0.25
                     MAR   3.4     2.4    0.5    1.8    0.38
                     APR   2.8     0.8    0.5    0.5    0.59
                     MAY   2.5     0.1    0.5    0.0    0.92
                     JUN   2.4     0.0    0.4    0.0    1.00
                     JUL   2.5     0.0    0.4    0.0    1.00
                     AUG   2.9     0.0    0.4    0.0    1.00
                     SEP   3.4     0.0    0.4    0.0    1.00
                     OCT   4.4     0.6    0.5    0.0    1.00
                     NOV   3.9     2.0    0.5    1.1    0.54
                     DEC   3.3     4.3    0.5    3.6    0.25
                      YR  38.3    18.3    5.6   13.8    0.42
```

Figure 132: F-CHART input and output files for Houston, TX.

```
Inputs           1  Number of collector panels....  6
For Collector    2  Collector panel area..........  20.2        FT2
                 3  FR*UL (test slope)............  .05         BTU/HR-FT2-F
                 4  FR*TAU*ALPHA (test intercept).  .42
                 5  Collector slope...............  90          DEG
                 6  Collector azimuth (South=0)...  0           DEG
                 7  Receiver orient (1=EW,2=NS)...  2
                 8  Inc angle mod (perpendicular).
                   1   .999   .998   .995   .981   .953   .882
                   .7   .35   0
                 9  Inc angle mod (parallel)......
                   1   .999   .998   .995   .981   .953   .882
                   .7   .35   0
                 10 Collector flowrate/area.......  11          LB/HR-FT2
                 11 Collector fluid specific heat.  1           BTU/LB-F
                 12 Modify test valuessss=Y,2=N)..  2
                 13   Test collector flowrate/area  11          LB/HR-FT2
                 14   Test fluid specific heat....  1           BTU/LB-F

Inputs           1  City call number..............  162
For System       2  Water storage volume..........  500         GALLONS
                 3  Building UA (0 for DHW only)..  240         BTU/HR-F
                 4  Fuel (1=EL,2=NG,3=OIL,4=OTHER)  1
                 5  Efficiency of fuel usage......  100         %
                 6  Domestic hot water (1=Y,2=N)..  1
                 7    Daily hot water usage.......  24          GALLONS
                 8    Water set temperature.......  110         F
                 9    Environment temperature.....  68          F
                 10   DHW storage tank size.......  204         GALLONS
                 11   UA of aux storage tank......  7.6         BTU/HR-F
                 12 Pipe heat loss (1=Y,2=N)......  2
                 13   Inlet pipe UA...............  5           BTU/HR-F
                 14   Outlet pipe UA..............  5           BTU/HR-F
                 15 Relative load HX size.........  1
                 16 Collector-storage HX (1=Y,2=N)  2
                 17   Tank side flowrate/area.....  11          LB/HR-FT2
                 18   Heat exchanger effectiveness  .5

Outputs                SOLAR   HEAT   DHW    AUX      F
                       MMBTU  MMBTU  MMBTU  MMBTU
                  JAN   5.4    3.6    0.5    2.2    0.47
                  FEB   5.1    3.1    0.5    1.9    0.48
                  MAR   5.0    1.5    0.5    0.6    0.71
                  APR   4.2    0.6    0.4    0.0    0.95
                  MAY   3.3    0.1    0.4    0.0    1.00
                  JUN   2.8    0.0    0.4    0.0    1.00
                  JUL   3.0    0.0    0.3    0.0    1.00
                  AUG   3.8    0.0    0.4    0.0    1.00
                  SEP   4.8    0.0    0.4    0.0    1.00
                  OCT   6.0    0.4    0.4    0.0    1.00
                  NOV   5.7    1.8    0.4    0.5    0.78
                  DEC   5.2    3.8    0.5    2.4    0.43
                   YR  54.3   14.9    5.1    7.6    0.62
```

Figure 133: F-CHART input and output files for Phoenix, AZ.

```
Inputs              1  Number of collector panels....  6
For Collector       2  Collector panel area..........  20.2        FT2
                    3  FR*UL (test slope)............  .05         BTU/HR-FT2-F
                    4  FR*TAU*ALPHA (test intercept).  .42
                    5  Collector slope...............  90          DEG
                    6  Collector azimuth (South=0)...  0           DEG
                    7  Receiver orient (1=EW,2=NS)...  2
                    8  Inc angle mod (perpendicular).
                     1   .999   .998   .995   .981   .953   .882
                     .7   .35   0
                    9  Inc angle mod (parallel)......
                     1   .999   .998   .995   .981   .953   .882
                     .7   .35   0
                    10 Collector flowrate/area.......  11          LB/HR-FT2
                    11 Collector fluid specific heat.  1           BTU/LB-F
                    12 Modify test valuessss=Y,2=N)..  2
                    13   Test collector flowrate/area  11          LB/HR-FT2
                    14   Test fluid specific heat....  1           BTU/LB-F

Inputs              1  City call number..............  16
For System          2  Water storage volume..........  500         GALLONS
                    3  Building UA (0 for DHW only)..  333         BTU/HR-F
                    4  Fuel (1=EL,2=NG,3=OIL,4=OTHER)  1
                    5  Efficiency of fuel usage......  100         %
                    6  Domestic hot water (1=Y,2=N)..  1
                    7    Daily hot water usage.......  29          GALLONS
                    8    Water set temperature.......  110         F
                    9    Environment temperature.....  68          F
                    10   DHW storage tank size.......  204         GALLONS
                    11   UA of aux storage tank......  7.6         BTU/HR-F
                    12 Pipe heat loss (1=Y,2=N)......  2
                    13   Inlet pipe UA...............  5           BTU/HR-F
                    14   Outlet pipe UA..............  5           BTU/HR-F
                    15 Relative load HX size.........  1
                    16 Collector-storage HX (1=Y,2=N)  2
                    17   Tank side flowrate/area.....  11          LB/HR-FT2
                    18   Heat exchanger effectiveness  .5

Outputs                  SOLAR   HEAT    DHW    AUX       F
                         MMBTU   MMBTU   MMBTU  MMBTU
                     JAN   3.9     7.9    0.7    7.2    0.17
                     FEB   3.7     5.9    0.6    5.2    0.21
                     MAR   3.9     4.7    0.7    4.1    0.25
                     APR   3.5     3.3    0.6    2.8    0.28
                     MAY   3.0     1.2    0.6    0.9    0.49
                     JUN   2.9     0.3    0.5    0.1    0.84
                     JUL   3.0     0.0    0.5    0.0    1.00
                     AUG   3.4     0.3    0.5    0.0    0.95
                     SEP   3.8     0.9    0.5    0.3    0.77
                     OCT   4.5     2.5    0.6    1.6    0.49
                     NOV   3.6     4.8    0.6    4.1    0.25
                     DEC   3.0     6.6    0.7    6.1    0.16
                      YR  42.4    38.5    7.2   32.4    0.29
```

Figure 134: F-CHART input and output files for Sterling, MD.

SOLAR DECATHLON 2007

220 ft2 of SunTech STP170 @ 25 deg. (Pitched roof)

							Solar kWh	XS kWh
1	City number for HOUSTON TX................	102		102		Jan	2089.3	205.7
2	Output: 1 for summary, 2 for detailed (Neg: graph)	1		1		Feb	2278.1	220.3
3	Cell temperature at NOCT conditions..............	113	F	45	C	Mar	2895.7	273.7
4	Array reference efficiency........................	0.133		0.133		Apr	3079.3	284.6
5	Array reference temperature.......................	77	F	25	C	May	3359.5	305.0
6	Max. power eff. temperature coeff. (times 1000)...	2.5	1/F	4.5	1/C	Jun	3396.2	303.5
7	Eff. of maximum power point tracking electronics..	0.9		0.9		Jul	3508	312.0
8	Efficiency of power conditioning electronics......	0.88		0.88		Aug	3470.9	309.0
9	Percent standard deviation of the load............	0	%	0	%	Sep	3147.4	284.0
10	Array area..	220	ft^2	20.4387	m^2	Oct	3088.1	285.5
11	Array slope.......................................	25	deg	25	deg	Nov	2325.7	222.4
12	Array azimuth (south=0)...........................	0	deg	0	deg	Dec	2002.7	195.8
						Yr	**34640.9**	**3201.6**

275 ft2 of Suntech STP170 @ 0 deg. (roof)

							Solar kWh	XS kWh
1	City number for HOUSTON TX................	102		102		Jan	2091.9	199.4
2	Output: 1 for summary, 2 for detailed (Neg: graph)	1		1		Feb	2411.1	230.1
3	Cell temperature at NOCT conditions..............	113	F	45	C	Mar	3340.2	314.4
4	Array reference efficiency........................	0.133		0.133		Apr	3813.9	352.6
5	Array reference temperature.......................	77	F	25	C	May	4434.2	403.0
6	Max. power eff. temperature coeff. (times 1000)...	2.5	1/F	4.5	1/C	Jun	4608.3	412.5
7	Eff. of maximum power point tracking electronics..	0.9		0.9		Jul	4696.8	418.2
8	Efficiency of power conditioning electronics......	0.88		0.88		Aug	4400.7	392.6
9	Percent standard deviation of the load............	0	%	0	%	Sep	3709.8	334.1
10	Array area..	275	ft^2	25.5483	m^2	Oct	3285.4	300.4
11	Array slope.......................................	0	deg	0	deg	Nov	2333.4	217.1
12	Array azimuth (south=0)...........................	0	deg	0	deg	Dec	1965.1	184.9
						Yr	**41090.7**	**3759.3**

68 ft2 MSK Light Thru (24 Cell) @ 90 deg.

							Solar kWh	XS kWh
1	City number for HOUSTON TX................	102		102		Jan	551.7	22.6
2	Output: 1 for summary, 2 for detailed (Neg: graph)	1		1		Feb	534.6	21.1
3	Cell temperature at NOCT conditions..............	113	F	45	C	Mar	548.2	20.3
4	Array reference efficiency........................	0.055		0.055		Apr	461.2	16.1
5	Array reference temperature.......................	77	F	25	C	May	405.8	14.1
6	Max. power eff. temperature coeff. (times 1000)...	2.5	1/F	4.5	1/C	Jun	374.3	13.3
7	Eff. of maximum power point tracking electronics..	0.9		0.9		Jul	400.5	13.8
8	Efficiency of power conditioning electronics......	0.88		0.88		Aug	465.5	15.4
9	Percent standard deviation of the load............	0	%	0	%	Sep	544.6	18.9
10	Array area..	68	ft^2	6.3174	m^2	Oct	694.7	25.9
11	Array slope.......................................	90	deg	90	deg	Nov	602.1	23.8
12	Array azimuth (south=0)...........................	0	deg	0	deg	Dec	548.1	22.3
						Yr	**6131.3**	**227.5**

68 ft2 MSK Light Thru (32 Cell) @ 90 deg.

							Solar kWh	XS kWh
1	City number for HOUSTON TX................	102		102		Jan	551.7	30.0
2	Output: 1 for summary, 2 for detailed (Neg: graph)	1		1		Feb	534.6	28.0
3	Cell temperature at NOCT conditions..............	113	F	45	C	Mar	548.2	27.0
4	Array reference efficiency........................	0.073		0.073		Apr	461.2	21.3
5	Array reference temperature.......................	77	F	25	C	May	405.8	18.8
6	Max. power eff. temperature coeff. (times 1000)...	2.5	1/F	4.5	1/C	Jun	374.3	17.6
7	Eff. of maximum power point tracking electronics..	0.9		0.9		Jul	400.5	18.3
8	Efficiency of power conditioning electronics......	0.88		0.88		Aug	465.5	20.5
9	Percent standard deviation of the load............	0	%	0	%	Sep	544.6	25.0
10	Array area..	68	ft^2	6.3174	m^2	Oct	694.7	34.4
11	Array slope.......................................	90	deg	90	deg	Nov	602.1	31.6
12	Array azimuth (south=0)...........................	0	deg	0	deg	Dec	548.1	29.7
						Yr	**6131.3**	**302.2**

68 ft2 MSK Light Thru (40 Cell) @ 90 deg.

							Solar kWh	XS kWh
1	City number for HOUSTON TX................	102		102		Jan	551.7	37.0
2	Output: 1 for summary, 2 for detailed (Neg: graph)	1		1		Feb	534.6	34.6
3	Cell temperature at NOCT conditions..............	113	F	45	C	Mar	548.2	33.3
4	Array reference efficiency........................	0.09		0.09		Apr	461.2	26.3
5	Array reference temperature.......................	77	F	25	C	May	405.8	23.2
6	Max. power eff. temperature coeff. (times 1000)...	2.5	1/F	4.5	1/C	Jun	374.3	21.7
7	Eff. of maximum power point tracking electronics..	0.9		0.9		Jul	400.5	22.6
8	Efficiency of power conditioning electronics......	0.88		0.88		Aug	465.5	25.2
9	Percent standard deviation of the load............	0	%	0	%	Sep	544.6	30.9
10	Array area..	68	ft^2	6.3174	m^2	Oct	694.7	42.4
11	Array slope.......................................	90	deg	90	deg	Nov	602.1	39.1
12	Array azimuth (south=0)...........................	0	deg	0	deg	Dec	548.1	36.6
						Yr	**6131.3**	**372.9**

100 ft2 MSK Photovol Glass @ 25 deg.

							Solar kWh	XS kWh
1	City number for HOUSTON TX................	102		102		Jan	947.8	32.8
2	Output: 1 for summary, 2 for detailed (Neg: graph)	1		1		Feb	1033.5	35.1
3	Cell temperature at NOCT conditions..............	113	F	45	C	Mar	1313.7	43.6
4	Array reference efficiency........................	0.055		0.055		Apr	1396.9	45.3
5	Array reference temperature.......................	77	F	25	C	May	1524.1	48.5
6	Max. power eff. temperature coeff. (times 1000)...	2.5	1/F	4.5	1/C	Jun	1540.7	48.3
7	Eff. of maximum power point tracking electronics..	0.9		0.9		Jul	1591.4	49.6
8	Efficiency of power conditioning electronics......	0.88		0.88		Aug	1574.6	49.2
9	Percent standard deviation of the load............	0	%	0	%	Sep	1427.8	45.2
10	Array area..	100	ft^2	9.2903	m^2	Oct	1401	45.4
11	Array slope.......................................	25	deg	25	deg	Nov	1055.1	35.4
12	Array azimuth (south=0)...........................	0	deg	0	deg	Dec	908.6	31.2
						Yr	**15715.1**	**509.6**

Figure 135: PVF-CHART input and output files for Houston, TX.

SOLAR DECATHLON 2007

							Solar kWh	XS kWh
	220 ft2 of SunTech STP170 @ 25 deg. (Pitched roof)							
1	City number for Phoenix AZ................	168		168		Jan	2852.2	275.8
2	Output: 1 for summary, 2 for detailed (Neg: graph)	1		1		Feb	3073.8	293.2
3	Cell temperature at NOCT conditions..............	113	F	45	C	Mar	3994.8	371.8
4	Array reference efficiency.......................	0.133		0.133		Apr	4501.8	407.7
5	Array reference temperature......................	77	F	25	C	May	4853.7	427.7
6	Max. power eff. temperature coeff. (times 1000)...	2.5	1/F	4.5	1/C	Jun	4734.1	406.2
7	Eff. of maximum power point tracking electronics..	0.9		0.9		Jul	4541	385.6
8	Efficiency of power conditioning electronics......	0.88		0.88		Aug	4480.3	382.9
9	Percent standard deviation of the load...........	0	%	0	%	Sep	4110.9	358.2
10	Array area.......................................	220	ft^2	20.4387	m^2	Oct	3846.9	347.4
11	Array slope......................................	25	deg	25	deg	Nov	3026.1	285.8
12	Array azimuth (south=0)..........................	0	deg	0	deg	Dec	2680.5	259.2
						Yr	**46696**	**4201.5**
	275 ft2 of Suntech STP170 @ 0 deg. (roof)							
1	City number for Phoenix AZ................	168		168		Jan	2551.2	233.4
2	Output: 1 for summary, 2 for detailed (Neg: graph)	1		1		Feb	3020.6	280.2
3	Cell temperature at NOCT conditions..............	113	F	45	C	Mar	4358.3	402.6
4	Array reference efficiency.......................	0.133		0.133		Apr	5379.8	487.2
5	Array reference temperature......................	77	F	25	C	May	6336.2	558.7
6	Max. power eff. temperature coeff. (times 1000)...	2.5	1/F	4.5	1/C	Jun	6402.7	550.2
7	Eff. of maximum power point tracking electronics..	0.9		0.9		Jul	6026.1	512.1
8	Efficiency of power conditioning electronics......	0.88		0.88		Aug	5555.1	475.3
9	Percent standard deviation of the load...........	0	%	0	%	Sep	4640.6	403.1
10	Array area.......................................	275	ft^2	25.5483	m^2	Oct	3826.9	339.7
11	Array slope......................................	0	deg	0	deg	Nov	2754.9	247.9
12	Array azimuth (south=0)..........................	0	deg	0	deg	Dec	2335.8	212.4
						Yr	**53188.1**	**4702.8**
	68 ft2 MSK Light Thru (24 Cell) @ 90 deg.							
1	City number for Phoenix AZ................	168		168		Jan	864.7	34.8
2	Output: 1 for summary, 2 for detailed (Neg: graph)	1		1		Feb	793.5	31.0
3	Cell temperature at NOCT conditions..............	113	F	45	C	Mar	815.9	29.8
4	Array reference efficiency.......................	0.055		0.055		Apr	676.8	22.5
5	Array reference temperature......................	77	F	25	C	May	530.9	16.5
6	Max. power eff. temperature coeff. (times 1000)...	2.5	1/F	4.5	1/C	Jun	452.3	14.0
7	Eff. of maximum power point tracking electronics..	0.9		0.9		Jul	487.7	15.1
8	Efficiency of power conditioning electronics......	0.88		0.88		Aug	605.1	18.9
9	Percent standard deviation of the load...........	0	%	0	%	Sep	756.6	25.4
10	Array area.......................................	68	ft^2	6.3174	m^2	Oct	956.8	35.1
11	Array slope......................................	90	deg	90	deg	Nov	887.3	34.8
12	Array azimuth (south=0)..........................	0	deg	0	deg	Dec	844.7	34.1
						Yr	**8672.3**	**312.1**
	68 ft2 MSK Light Thru (32 Cell) @ 90 deg.							
1	City number for Phoenix AZ................	168		168		Jan	864.7	46.3
2	Output: 1 for summary, 2 for detailed (Neg: graph)	1		1		Feb	793.5	41.2
3	Cell temperature at NOCT conditions..............	113	F	45	C	Mar	815.9	39.5
4	Array reference efficiency.......................	0.073		0.073		Apr	676.8	29.9
5	Array reference temperature......................	77	F	25	C	May	530.9	21.9
6	Max. power eff. temperature coeff. (times 1000)...	2.5	1/F	4.5	1/C	Jun	452.3	18.7
7	Eff. of maximum power point tracking electronics..	0.9		0.9		Jul	487.7	20.1
8	Efficiency of power conditioning electronics......	0.88		0.88		Aug	605.1	25.1
9	Percent standard deviation of the load...........	0	%	0	%	Sep	756.6	33.7
10	Array area.......................................	68	ft^2	6.3174	m^2	Oct	956.8	46.6
11	Array slope......................................	90	deg	90	deg	Nov	887.3	46.3
12	Array azimuth (south=0)..........................	0	deg	0	deg	Dec	844.7	45.4
						Yr	**8672.3**	**414.7**
	68 ft2 MSK Light Thru (40 Cell) @ 90 deg.							
1	City number for Phoenix AZ................	168		168		Jan	864.7	57.2
2	Output: 1 for summary, 2 for detailed (Neg: graph)	1		1		Feb	793.5	50.9
3	Cell temperature at NOCT conditions..............	113	F	45	C	Mar	815.9	48.8
4	Array reference efficiency.......................	0.09		0.09		Apr	676.8	36.9
5	Array reference temperature......................	77	F	25	C	May	530.9	27.0
6	Max. power eff. temperature coeff. (times 1000)...	2.5	1/F	4.5	1/C	Jun	452.3	23.0
7	Eff. of maximum power point tracking electronics..	0.9		0.9		Jul	487.7	24.8
8	Efficiency of power conditioning electronics......	0.88		0.88		Aug	605.1	30.9
9	Percent standard deviation of the load...........	0	%	0	%	Sep	756.6	41.7
10	Array area.......................................	68	ft^2	6.3174	m^2	Oct	956.8	57.5
11	Array slope......................................	90	deg	90	deg	Nov	887.3	57.1
12	Array azimuth (south=0)..........................	0	deg	0	deg	Dec	844.7	56.0
						Yr	**8672.3**	**511.8**
	100 ft2 MSK Photovol Glass @ 25 deg.							
1	City number for Phoenix AZ................	168		168		Jan	1296.3	44.0
2	Output: 1 for summary, 2 for detailed (Neg: graph)	1		1		Feb	1397	46.7
3	Cell temperature at NOCT conditions..............	113	F	45	C	Mar	1815.6	59.2
4	Array reference efficiency.......................	0.055		0.055		Apr	2046.1	64.9
5	Array reference temperature......................	77	F	25	C	May	2206	68.1
6	Max. power eff. temperature coeff. (times 1000)...	2.5	1/F	4.5	1/C	Jun	2151.7	64.6
7	Eff. of maximum power point tracking electronics..	0.9		0.9		Jul	2063.9	61.4
8	Efficiency of power conditioning electronics......	0.88		0.88		Aug	2036.3	60.9
9	Percent standard deviation of the load...........	0	%	0	%	Sep	1868.4	57.0
10	Array area.......................................	100	ft^2	9.2903	m^2	Oct	1748.4	55.3
11	Array slope......................................	25	deg	25	deg	Nov	1375.4	45.6
12	Array azimuth (south=0)..........................	0	deg	0	deg	Dec	1218.3	41.3
						Yr	**21223.4**	**668.9**

Figure 136: PVF-CHART input and output files for Phoenix, AZ.

SOLAR DECATHLON 2007

220 ft2 of SunTech STP170 @ 25 deg. (Pitched roof)

							Solar kWh	XS kWh
1	City number for BALTIMORE MD...............	20		20		Jan	1871.6	191.6
2	Output: 1 for summary, 2 for detailed (Neg: graph)	1		1		Feb	2086	212.2
3	Cell temperature at NOCT conditions..............	113	F	45	C	Mar	2820	278.5
4	Array reference efficiency.......................	0.133		0.133		Apr	3158.8	303.7
5	Array reference temperature......................	77	F	25	C	May	3499.4	327.9
6	Max. power eff. temperature coeff. (times 1000)...	2.5	1/F	4.5	1/C	Jun	3626	331.6
7	Eff. of maximum power point tracking electronics..	0.9		0.9		Jul	3705.2	335.1
8	Efficiency of power conditioning electronics......	0.88		0.88		Aug	3453.2	314.1
9	Percent standard deviation of the load...........	0	%	0	%	Sep	2987.9	277.1
10	Array area......................................	220	ft^2	20.4387	m^2	Oct	2593.1	250.0
11	Array slope.....................................	25	deg	25	deg	Nov	1881.7	186.3
12	Array azimuth (south=0)..........................	0	deg	0	deg	Dec	1623.6	164.6
						Yr	**33306.5**	**3172.8**

275 ft2 of Suntech STP170 @ 0 deg. (roof)

1	City number for BALTIMORE MD...............	20		20		Jan	1635	156.5
2	Output: 1 for summary, 2 for detailed (Neg: graph)	1		1		Feb	2031.6	198.8
3	Cell temperature at NOCT conditions..............	113	F	45	C	Mar	3053.9	297.4
4	Array reference efficiency.......................	0.133		0.133		Apr	3723.9	357.2
5	Array reference temperature......................	77	F	25	C	May	4441.7	415.8
6	Max. power eff. temperature coeff. (times 1000)...	2.5	1/F	4.5	1/C	Jun	4730.4	432.8
7	Eff. of maximum power point tracking electronics..	0.9		0.9		Jul	4767	431.1
8	Efficiency of power conditioning electronics......	0.88		0.88		Aug	4194.1	380.5
9	Percent standard deviation of the load...........	0	%	0	%	Sep	3334.7	307.1
10	Array area......................................	275	ft^2	25.5483	m^2	Oct	2585.8	242.3
11	Array slope.....................................	0	deg	0	deg	Nov	1703.7	158.9
12	Array azimuth (south=0)..........................	0	deg	0	deg	Dec	1395.7	131.3
						Yr	**37597.5**	**3509.7**

68 ft2 MSK Light Thru (24 Cell) @ 90 deg.

1	City number for BALTIMORE MD...............	20		20		Jan	599	25.8
2	Output: 1 for summary, 2 for detailed (Neg: graph)	1		1		Feb	566.9	23.9
3	Cell temperature at NOCT conditions..............	113	F	45	C	Mar	620.6	24.6
4	Array reference efficiency.......................	0.055		0.055		Apr	551.8	20.6
5	Array reference temperature......................	77	F	25	C	May	500.5	17.8
6	Max. power eff. temperature coeff. (times 1000)...	2.5	1/F	4.5	1/C	Jun	473.1	16.3
7	Eff. of maximum power point tracking electronics..	0.9		0.9		Jul	503.2	17.1
8	Efficiency of power conditioning electronics......	0.88		0.88		Aug	554.4	19.3
9	Percent standard deviation of the load...........	0	%	0	%	Sep	605.3	22.3
10	Array area......................................	68	ft^2	6.3174	m^2	Oct	669.8	26.6
11	Array slope.....................................	90	deg	90	deg	Nov	574.9	23.8
12	Array azimuth (south=0)..........................	0	deg	0	deg	Dec	534.5	22.9
						Yr	**6754**	**261.0**

68 ft2 MSK Light Thru (32 Cell) @ 90 deg.

1	City number for BALTIMORE MD...............	20		20		Jan	599	34.3
2	Output: 1 for summary, 2 for detailed (Neg: graph)	1		1		Feb	566.9	31.7
3	Cell temperature at NOCT conditions..............	113	F	45	C	Mar	620.6	32.7
4	Array reference efficiency.......................	0.073		0.073		Apr	551.8	27.4
5	Array reference temperature......................	77	F	25	C	May	500.5	23.7
6	Max. power eff. temperature coeff. (times 1000)...	2.5	1/F	4.5	1/C	Jun	473.1	21.6
7	Eff. of maximum power point tracking electronics..	0.9		0.9		Jul	503.2	22.8
8	Efficiency of power conditioning electronics......	0.88		0.88		Aug	554.4	25.7
9	Percent standard deviation of the load...........	0	%	0	%	Sep	605.3	29.6
10	Array area......................................	68	ft^2	6.3174	m^2	Oct	669.8	35.3
11	Array slope.....................................	90	deg	90	deg	Nov	574.9	31.7
12	Array azimuth (south=0)..........................	0	deg	0	deg	Dec	534.5	30.4
						Yr	**6754**	**346.8**

68 ft2 MSK Light Thru (40 Cell) @ 90 deg.

1	City number for BALTIMORE MD...............	20		20		Jan	599	42.3
2	Output: 1 for summary, 2 for detailed (Neg: graph)	1		1		Feb	566.9	39.2
3	Cell temperature at NOCT conditions..............	113	F	45	C	Mar	620.6	40.3
4	Array reference efficiency.......................	0.09		0.09		Apr	551.8	33.8
5	Array reference temperature......................	77	F	25	C	May	500.5	29.2
6	Max. power eff. temperature coeff. (times 1000)...	2.5	1/F	4.5	1/C	Jun	473.1	26.7
7	Eff. of maximum power point tracking electronics..	0.9		0.9		Jul	503.2	28.1
8	Efficiency of power conditioning electronics......	0.88		0.88		Aug	554.4	31.7
9	Percent standard deviation of the load...........	0	%	0	%	Sep	605.3	36.6
10	Array area......................................	68	ft^2	6.3174	m^2	Oct	669.8	43.6
11	Array slope.....................................	90	deg	90	deg	Nov	574.9	39.1
12	Array azimuth (south=0)..........................	0	deg	0	deg	Dec	534.5	37.5
						Yr	**6754**	**428.0**

100 ft2 MSK Photovol Glass @ 25 deg.

1	City number for BALTIMORE MD...............	20		20		Jan	849.1	30.5
2	Output: 1 for summary, 2 for detailed (Neg: graph)	1		1		Feb	946.3	33.8
3	Cell temperature at NOCT conditions..............	113	F	45	C	Mar	1279.3	44.4
4	Array reference efficiency.......................	0.055		0.055		Apr	1433	48.3
5	Array reference temperature......................	77	F	25	C	May	1587.5	52.2
6	Max. power eff. temperature coeff. (times 1000)...	2.5	1/F	4.5	1/C	Jun	1645	52.8
7	Eff. of maximum power point tracking electronics..	0.9		0.9		Jul	1680.9	53.3
8	Efficiency of power conditioning electronics......	0.88		0.88		Aug	1566.6	50.0
9	Percent standard deviation of the load...........	0	%	0	%	Sep	1355.5	44.1
10	Array area......................................	100	ft^2	9.2903	m^2	Oct	1176.4	39.8
11	Array slope.....................................	25	deg	25	deg	Nov	853.7	29.7
12	Array azimuth (south=0)..........................	0	deg	0	deg	Dec	736.6	26.3
						Yr	**15109.8**	**505.2**

Figure 137: PVF-CHART input and output files for Sterling, MD.

Appendix C - Final Pictures of the TAMU Solar House

Figure 138: Final view of the TAMU SD House (South façade) (photo by John Peters).

Figure 139: Final view of the TAMU SD house (west façade) (photo by John Peters).

Appendix D - Daily Blog Documentation

The following material was posted to the Texas A&M University Solar Decathlon web site each day to allow students, the faculty and staff to know what was going on at the National Mall. The text shown and selected photos were used to let Aggies know how their team-mates were progressing (or not) during the construction and competition.

Thursday, Oct. 4, 2007

Construction has been under way for 32 hours and the project is moving forward nicely. All of the GroWalls that attach to the core are installed and the electrical is connected but not energized. The garage is about 90% framed and its mechanical GroWall is being installed. There was a hang-up on the routing of the piping out of that GroWall that had to be resolved and all of the lines had to be re-routed around a column. Chris Urban, our plumber, started on that change at 8 a.m. today and should have it corrected within a couple of hours. In addition, the first two bays of solar panel were erected, so installation can commence on wiring up the solar power generation system. The day shift has been tasked with erecting the steel for the study, and completing the garage. The evening shift's job will be to frame the deck from the garage to the study, which will allow for the erection of the solar thermal water heaters. Once this is done, all the piping can be routed for solar water heating and distribution. The young people are working long and hard. Many of the team members are working their shift plus half of another. The area where we are staying in shuts down at 7 p.m. This is difficult for nocturnal college students who are accustomed to restaurants staying open until 2 a.m.

Friday, Oct. 5, 2007

The remaining PV panels were placed on the roof, the garage was completed, the cabinet for the domestic hot water heaters was placed, and work on its mechanical GroWall continued. Progress was also made toward rerouting the plumbing around the column and upward to the cabinet that houses the domestic hot water tank. The decking was installed on several sides of the house and the framing for the study was completed. Framing for the solar thermal wall was roughed-in, which included a few modifications to several joints to account for some unevenness on-site.

Saturday, Oct. 6, 2007

More decking was placed around the building and the substructure was put down for use under the ponds on the north side of the building after the truck arrived back from the local supply store with new materials. The wind screens and solar thermal manifolds were placed on the frame, which was roughed-in on Friday. Insulated copper piping was installed from collector to collector and the insulated supply and return lines were fabricated and put in place. Also the plumbing from the GroWalls was threaded underneath the house back to the mechanical GroWall on the garage, awaiting final connection to the pumps and controllers. The 24 - 2 volt batteries, which each weight 210 pounds, were placed in their trays beside the garage. They will be used to store the energy from the PV. The 6,000 pounds of energy storage was purposefully oversized to allow for the house to function for up to one week under complete overcast conditions -- something that happened at the 2005 Solar Decathlon. Wind screens were also added to the study, and the solar thermal tank insulated.

Sunday, Oct. 7, 2007

The plumbing supply connections were completed from all the GroWalls back to the mechanical GroWall on the garage and the solar thermal collectors were connected to the solar thermal storage tank, located in the mechanical GroWall. There was a small problem with the supply water tank, which was rendered unusable when welding sparks melted it. Luckily, some Aggie creativity came up with a solution to replace the tank with the waste water tank (about the same size), and purchase a new waste water tank. This allowed the house to accept water from DOE on Monday, and bought a little time to purchase a new tank to replace the waste water tank. Additionally, the batteries were wired into the inverters, and the AC system was checked out by the DOE inspectors -- a required formality before the house is allowed to power up. Doors for the house were also installed. The evacuated tubes were placed into the solar thermal manifold on Sunday evening and covered with blankets to protect them from thermal shock on Monday when the water arrives. The thermal shock can shatter the tubes when they are hot from sitting in the sun and cold water is pumped into the manifold. The solar controls were also connected.

Monday, Oct. 8, 2007

Today was a big day for the Aggie team. First, the water arrived from the sponsors, which was used to fill the water supply tank, solar thermal storage tank and the ponds that surround the north side of the house. Unfortunately, there are a few pinhole leaks in the supply tank that require some attention. The solar thermal loop was put into service in the late afternoon, and is now up and running. In a few hours it raised the temperature of the solar thermal tank from 68 to 80 F. Tomorrow we should see some real heating out of the collector array. The kitchen sink and dishwasher have been plumbed. The mirror for the bathroom sink is to be shipped overnight from a College Station supplier and will be installed Tuesday. After the mirror arrives, the sink can be installed and plumbed, which completes all the plumbing on the house (whew!).

Almost all of the decking is in place, and the ponds have been filled with water. The entry and exit ramps are now being constructed and put into place. Other than the power for the hand tools, all other electricity in the house is now coming from the batteries/PV. The final connections from the PV panels into the batteries need to be completed tonight or early tomorrow. Once this is done the "big" electrical loads can be fired up and tested, including the electric water heaters (just in case there's no sun), the clothes dryer, heat pump, stove, electric car and dishwasher. Special software will be used to record and display minute-by-minute power flows so the team can better understand how electricity is being generated by the sun, or used by the appliances, etc.

Tuesday, Oct. 9, 2007

The Aggie Solar Decathlon team made some great strides toward the finish line. The pinhole leaks in the water supply tank are being kept at bay with duct tape as the team shops for a replacement. The PV connections to the batteries are almost complete. Once this is finished, the system will be fully operational and testing of the large, power-consuming systems can begin. The final inspection on the plumbing/solar thermal systems called for minor modifications to the pump placements and for extending the drain tube on the pressure and relief valve from the water heater. This should be accomplished shortly. The mounting of the building integrated photovoltaics (BIPV) remain on hold while a suitable mechanical fastener is sought.

The screens are up on the study, and all of the rain screens have been placed, with the exception of one on the garage, which requires a removable mounting to provide access to the electric water heater cabinet. The daylight reflecting panels are in place, the venetian blinds have been installed and final work has begun on the cabinets, fixtures, etc. Work continues on the bench that covers the batteries and the ramps leading to the building. Plants are also being placed in their respective locations, including the ponds on the north side.

Wednesday, Oct. 10, 2007

Rough waters on Wednesday for the Aggie team. During the process of moving the HVAC GroWall from Texas to D.C., the 24 VAC transformer that provides power to the thermostat was damaged, which resulted in a system failure Wednesday morning during the initial tests. Several phone calls to the GE engineer in Louisville, KY, identified the problem, and tests were performed to verify the problem. A new transformer is being Fed Expressed for Thursday morning delivery to be installed to final testing can be completed just in time for the mandatory completion of the construction on Thursday evening and Grand Opening on Friday when the general public gets their first look at our house. Then judging and testing begins on Sunday, October 13, and continues through Friday October 19 when the winner is announced. Testing of the other appliances is under way. Other minor adjustments were needed on

Wednesday as well, including repriming the pump for the solar collector loop, since an air bubble was causing the pump to cavitate and lose its water circulation. The construction on the ramp is almost finished. Most of the decking is in place and rails are being installed. The bench that covers the batteries has been framed and the top of the bench completed, leaving only the sides to be finished. Work on the interior is almost finished. All appliances are all in place and connected and the final touch-up of the cabinets is being completed. Furniture will be placed on Thursday after all protective covering is removed from the flooring (including the leather entryway) and appliances. Work continues on mounting the building integrated photovoltaic panels (BIPV). Once these are mounted they will be connected to the charge controllers, which complete the PV installation.

Thursday, Oct. 11, 2007

Today was a sprint to the finish, just in time for a press conference and an unofficial early opening at 5 p.m.! Tomorrow is the official opening ceremony at 10 a.m., following which will be large throngs of eager visitors. Thursday also meant tons of cleanup (literally), getting all construction materials picked-up and moved off-site, moving the generators, cleaning the glass, watering the plants, putting the furniture in (at the very last), mounting the wind turbines (yes, wind turbines), finishing the ramp and battery bench, touching up the paint job here and there and fixing the last minute problems, of which there were several. The problem with the 24 VAC transformer turned out to be a pinched wire between the thermostat and the heat pump/air conditioner. This was fixed by pulling new thermostat wire. Good thing we used conduit! The heat pump modes have all been tested, and final programming of the thermostat will need to proceed tonight, once the tours are completed. The holes in the water supply tank were repaired and the tank placed back into service. Unfortunately, the final appliance testing remains on hold due to another pinhole leak in pressure regulator that forces the pressurization pump to turn on-off-on-off...not exactly what is wanted for the long term operation. The solar collectors were up and running all day, providing a full tank of 130+ °F water in the storage tank, and this on a cloudy day. Higher temperatures are expected if the sun breaks through the clouds. The building integrated photovoltaics (BIPV) are mounted, and connections will be completed to night.

Currently, there is so much energy in the batteries that the team actually had to bleed-off a little power, which was accomplished by running the arc welder from the PV, which was being run by the generator! Otherwise, the Aggie Solar Decathlon house is up and running and sight to behold!

Contest judging begins on Saturday with the architectural judging, followed by communications, lighting, marketing, etc. Winners of each contest are announced separately, and the Grand Winner announced at the end of the competition.
PS: It's not too late to get your tickets to D.C. to see the Solar Decathlon this weekend!

Friday, Oct.13, 2007

Today started with a military color guard followed with a ribbon-cutting by Secretary of Energy Samuel Bodman at 10 a.m. Each team was introduced to the crowd for photos and a handshake with the secretary, and the Solar Village was declared officially open! Then the crowds came, including members of Congress, foreign dignitaries, and lots and lots and lots of eager sightseers asking 1,000s of questions. The Texas A&M house was a sight to see, everything was completed and in its place. The sun was shining, the PV panels were producing electricity, and gentle breeze blew across our wind turbines, which brought lots of compliments from the visitors. However, this did not deter our house from breaking down. It started with our solar collector array. Unfortunately, this was not turned on early enough to prevent the formation of steam in the line, which prevents water flow by the normal circulation pump. This was resolved by roping off the array, climbing up on the ladder, releasing the steam, purging the line with a larger pump, and restarting the normal circulation pump -- all of which had to be done as the crowds passed by asking questions. Then, no matter what we did, we could not get the main pressurization pump to stop chattering -- literally, on-off-on-off. It was annoying. A call to the ITT/Gould engineer identified a possible failure in the pressure switch for reasons unknown, which will be remedied with a new pump and perhaps relocating the pump to provide a better position in regards to the water supply located below the deck. Then there was the issue of our beautifully designed decks and ramps, which were rejected by the ADA code officials.

Apparently, gravel was o.k. on the ground, but it was not o.k. between the deck panels - go figure! So stay tuned, we'll have a fix for the decks, ramp and pump by tomorrow at 10 a.m. when the tours start again.

Gig'em! Whoop!

Saturday, Oct.13, 2007

Patience they say is a virtue, and the Aggies were definitely virtuous today. Saturday was a day of huge crowds at the Solar Decathlon. Throngs of people waited in long lines to see the houses on display. The Aggie house was unique with its wind turbines staring down at the crowds below that were eager to see what was inside, but were blocked from entering the house because the handicap ramp did not meet the strict ADA compliance. Only the Solar Decathlon architecture jury was allowed to view the Aggie house on Saturday. They say when you have an abundance of lemons, make lemonade. So the Aggies made concrete with the abundant gravel on Saturday morning and afternoon that was rejected by the ADA Safety Officer as a tripping hazard and painstakingly replaced the gravel troughs with concrete-filled troughs. Then the incline on the ramp was adjusted (several times) until it was satisfactory (once more please). Next, all the railing was replaced with ADA-compliant railing, which required a dash to the store, measuring, cutting and welding on-site using the electricity stored in the 6,000 lbs of batteries the house contains, to the amazement of onlookers. Then, over 800 lbs of water were purchased, driven to the site, carried by hand and poured into water supply tank to replace the water lost through the pinhole leaks last week. Finally, more new parts were purchased for installation Saturday afternoon and Sunday morning, including a new pressurization control for the main pump, a new, high temperature pump for the solar array, and a new thermostat for the heat pump. All are hoping Sunday is a better day when the solar village reopens so the eager crowds will be given their chance to see the Aggie’s fantastic, reconfigurable, ADA-compliant house.

Sunday, Oct. 14, 2007

Patience paid off for the Aggies. By Sunday at 10 a.m. all ramps, stairs and railings were revamped with ADA-compliant versions, which pleased the on-site safety officer who then declared the house officially “open for tours,” just in time for the eager crowds that had assembled to see what many called “one of the most spectacular houses in the solar village.” During the tours, work continued on the main pressurization pump replacement. Several of the visitors were more interested in the repairs under way than in the fine trimmings on the groHome. One even exclaimed “you can actually repair this house yourself!” Little did they know about the ordeal that the team has endured the last few days. After the repairs were completed to the main pump, the house’s plumbing system was then certified by DOE’s inspectors for full operation. The solar thermal system reached 173 F under clear skies using the temporary pump. A replacement pump will be installed tonight after the sun goes down and the crowds disburse. It appears that the original pump was damaged by steam that formed in the array earlier in the week. The photovoltaic (PV) system was working so well on Sunday that it had electricity to spare. This is partially due to the fact that the Aggie team is not running the groHome's air conditioner because the house was been wide open for tours. The electric car, however, is now fully charged, so the Aggies have a full charge on the battery bank as they head into a week of contests. This is a good thing. In the 2005 Solar Decathlon, there was little sun for most of the assembly period, which reduced the contest into a battle of who had the most electricity in their batteries.

Monday through Friday of next week, the house will be put through a series of “contests” that test the house systems' performance. These include washing/drying towels, boiling water, keeping the groHome space heated or cooled, putting some miles on the electric car, cooking meals, etc. On Monday, the Solar Decathlon's architectural winner will be announced, and the other individual awards will follow in the remaining days until Friday, when the overall winner is announced. Of course we're hoping they'll have the initials T.A.M.U.!

Monday, Oct. 15, 2007

Monday was a day of contests, as well as more visitors, including more panels of judges. Today the judges inspected the house's lighting/daylighting systems. Today's tests included shower tests, dishwasher tests, water boiling tests, and a test to see how many miles one can put on the electric car. The shower tests included two tests where a specified amount of hot water must be delivered to the shower in a set period of time; one test in the morning and one in the afternoon. In the dishwasher test, a plate is placed in the dishwasher with a special piece of tape, and the dishwasher runs through its complete cycle. The tape on the plate records the proper operation by changing color. There was also a water boiling test where 5 lbs of water must be completely boiled away. Ongoing temperature measurements are also made of the refrigerator, freezer and temperature/humidity measurements are made of the heating and cooling systems. These will be studied later in the week to determine if temperatures and humidities are being kept within their required range.

The Aggies did well on all the tests except the first shower test in the morning, where a improperly set valve prevented the last few gallons of hot water from reaching the shower in a timely fashion. This was resolved for the afternoon shower test, which worked perfectly. We were told that other teams struggled with these tests and that over half of the teams had one problem or another and some had multiple problems. On Monday, the winner of the architectural contest was announced -- the Darmstadt University of Technology, or “Technische Universitat of Darmstadt,” from Darmstadt, Germany. The University of Maryland placed second, and the Universidad Politécnica de Madrid placed third. Unfortunately, not having the ADA compliant ramps properly completed on time did not sit well with the judges who awarded the Aggies 16th place (Otherwise, we’re sure we would have won!). The University of Texas at Austin placed ninth. So, we’ve got our work cut out for us. Tuesday, more tests will be performed on the house’s systems, and more miles put on the electric car. Our team is looking good, feeling rested and ready to carry the day tomorrow. Our house is performing well, and should finish the week in good shape barring anymore unforeseen problems. On Tuesday the winner of the Communications contest will be announced.

Tuesday, Oct. 16, 2007

Tuesday was another day of contests, more visitors, and more judges. Today's tests included two shower tests, a dishwasher test, washing and drying of towels, and another race to see how many miles can be put on the electric car. TAMU is averaging more than 40 miles per day, which is on par with all the other teams except Colorado, who has managed to put 80 miles per day on their car. In place of boiling five pounds of water on Tuesday, the Aggies prepared dinner for eight people, including guests from the Santa Clara team, Spain and Puerto Rico. The menu? -- Tex-Mex of course! The Aggies did well on all of Tuesday's tests. This will help them gain overall points since some of the other teams continue to struggle with their tests because of mechanical failures. On Tuesday, the University of Maryland was named winner of the communication contest. Santa Clara placed second, Penn State, third, and the University of Texas placed fourth. The Aggies were in good company at 17th place, which was ahead of 18th place University of Colorado, 19th place MIT, and 20th place Carnegie Mellon. How these contests are being scored remains a topic of great discussion. Our team continued to shine, and our house continued to perform well on Tuesday. The Aggie house is a real attraction on the mall, as it is the only house with wind turbines, which has brought us more than our share of press interviews. Wednesday our work continues as more tests will be performed on the house's systems, more miles put on the electric car, more visitors and more judges.

Wednesday, Oct. 17, 2007

Wednesday the houses were closed to the public so that the teams could continue with their contests, which included washing more towels, boiling more water, two more shower tests and driving the electric cars. During these tests, temperature and humidity measurements continued to determine if the heating/cooling systems were performing to specifications. The Aggies did well on the contests on Tuesday, finishing in second place on the appliance contests and managed to get 50 miles on their car verses 40 on Monday. This moved their status up one notch to 15th place from 16th place on Monday, now ahead of 16th-place Cincinnati, Carnegie Mellon (17th), MIT (18th), Missouri-Rolla (19th) and Lawrence Tech (20th). Maryland, Darmstadt and Penn State were ranked first, second and third overall on Wednesday morning. The University of Texas was sitting at fifth place.

On Wednesday, the University of Maryland won the lighting contest. Darmstadt finished second, and Montreal, third. The Aggies finished 17th on the lighting contest right behind MIT and ahead of Cincinnati, Puerto Rico, and Georgia Tech. On Thursday, the winner for the marketing contest will be announced and the houses will be open to the public. Also, the engineering jury will tour the houses to interview each team's understanding of their design. Appliance contests and measurements will continue, and more miles will be logged on the electric cars. The Aggies should do well on the engineering contest, as evidenced by their second-place finish on the appliance test. Check back tomorrow for details.

Thursday, Oct. 18, 2007

Thursday was challenging day, as it was cloudy much of the day, which provided little of the important sunshine to recharge batteries and the thermal storage. The houses were open to the public again, and the contests continued, which included washing more towels, boiling more water, two more shower tests, and driving the electric cars, as well as more temperature and humidity measurements to determine if systems were performing. The Aggies did well on the contests on Wednesday, moving into 14th place, ahead of Kansas (15th place), Missouri-Rolla (16th place), MIT (17th place), Carnegie Mellon (18th place), Cincinnati (19th place), and Lawrence Tech (20th place). Maryland, Darmstadt and Penn State are still on top at first, second and third overall as of Thursday night. The University of Texas dropped down one notch to 6th place. On Thursday, Illinois won the market viability contest, followed by Maryland in second place and Penn State in third. Texas A&M placed seventh in this event, ahead of ninth-place University of Texas. Also on Thursday, the engineering jury toured the house and asked lots of questions about its engineering design -- how the house functions, errors that were made and even what the team might do differently next time? The Aggies did well on the contests on Thursday, which should help in their overall scores.

Friday will be a challenge for all the teams, since cloudy weather and rain are again predicted for the Washington, D.C., area. Friday will also be a special challenge for the Aggies, since their dehumidifier ran more than expected on Wednesday night, draining precious electricity from their batteries. On Friday morning they'll need every Watt-hour they can spare to complete the contests and coast to the finish at noon. On Friday the pace is expected to pick up. The engineering jury will complete its tours of the houses in the morning, and more contests will be performed through noon. At 2 p.m. the winner of the engineering contest will be announced, followed shortly thereafter by the announcement of the overall winner.

Saturday, the houses will be open to the public 10 a.m. - 5 p.m. when the 2007 Solar Decathlon officially winds to a close. Then comes the arduous task of disassembling the Aggie groHome for its trip back to College Station.

Friday, Oct. 19, 2007

The Solar Decathlon competition wrapped up Friday with Technische Universitat Darmstadt, Germany earning first place honors, followed by the University of Maryland in second place and Santa Clara University in third. Texas A&M finished 17th, ahead of Kansas (18th), Cornell (19th), and Lawrence Tech (20th). The University of Texas dropped to a 10th place finish and last year's winner, the University of Colorado, earned seventh place.

The Aggies scored well on the appliance contest (1st place), the market viability contest (8th place), and the comfort, hot water and getting around contests (9th place for each). Unfortunately, the depletion of the batteries on Wednesday evening by the dehumidifier robbed them of the electricity needed to finish strong on Friday.

Saturday the houses will be open for public viewing 10 a.m.-5 p.m., then the teams will pack up their houses and head home. Most are planning to reassemble at their respective entries in new locations close to home.

AWARDS:

- 1st place in the American Institute of Architects-Students/American Institute of Architects Committee on the Environment Award
- 1st place award for the National competition referred to as the Lifecycle Challenge award sponsored by US EPA
- 1st place in the Solar Decathlon Appliances contest
- 3rd place in DOE Curb Appeal from the National Association of Home Builders
- Chosen among 20 teams for a Sundance channel documentary
- Received an award for achieving the hottest water temperatures at the solar village.

Vita

Mr. Eduardo J. Ramirez was born on June 3, 1982, in Caguas, Puerto Rico to Hector A. Ramirez and Luz M. Rivera. Mr. Ramirez graduated from Notre Dame High School in Caguas in 2000. He received his Bachelor of Science degree in Mechanical Engineering from the University of Puerto Rico at Mayaguez in 2005. In January 2006, he enrolled at Texas A&M University in order to complete the requirements for a Master of Science degree. After a change in career goals, he decided to earn a Master of Engineering degree. Mr. Ramirez wed Lynette M. Davila on February 21, 2008. After graduating in May, 2008, he and Lynette will move to the city of Houston, Texas, to work as a Mechanical Engineer with Wylie Consulting Engineers.